Ad Hoc Participation in Situation Assessment: Supporting Mobile Collaboration in Emergencies

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Emergencies are characterized by high complexity and unpredictability. In order to assess and manage them successfully, improvisation work and informal communication, even beyond local and organizational boundaries, is needed. Such informal practices can facilitate ad hoc participation of units in situation assessment, but this may lack overall situation awareness. This article presents a study on how emergent "collaboration needs" in current work of response teams located on-site and in the control center could be supported by mobile geo-collaboration systems. First, we present the results of an empirical study about informal work and mobile collaboration practices of emergency services. Then we describe the concept of a mobile geo-collaboration system that addresses the aspects detected in the empirical study and that was implemented as an Android application using web sockets, a technology enabling full-duplex ad hoc communication. Finally, we outline the findings of its evaluation in practice and its implications.

Categories and Subject Descriptors: H.5.3 [**Group and Organization Interfaces**]: Computer-supported cooperative work.

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Additional Key Words and Phrases: Awareness, collaboration, design case study, emergency management, ethnography, mobile devices, participation, situation assessment

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1. INTRODUCTION

During disasters, emergency services and crisis managers are confronted with situations for which decisions have to be made fast. The speed of the decision-making process is often directly connected to devastating (e.g., save human lives), economic (e.g., extinguish a burning factory) or ecological (e.g., stop escaping oil) consequences. Whatever the incident is—a hurricane, flood, or technical accident—the officer in charge has to assess the situation as quickly as possible to be able to use the available resources for making useful decisions. Assessing a situation is a very cooperative process, because most of the needs that arise in emergencies cannot be completely covered by routine processes and previously predicted information demands [Ley et al. 2012]. The necessary information is often not available in a centralized manner, but instead has to be requested from the control center, special relief forces, or from a third party [Ludwig

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et al. 2013; Nilsson and Støle 2010] for getting an appropriate "situation awareness." According to Endsley [1995] *situation awareness* refers to the "state of knowledge," whereas *situation assessment* to the "process of achieving, acquiring, or maintaining" information. Geospatial data such as the location of dangers, resources, or field operations is particularly important for the process of situation assessment and therefore establishing situation awareness. This information is typically managed on situation maps by the operations management in the control center and on site by the head of a section. Complicating matters, in an actual crisis, there is often no prior definition of who the collaborators will be and when collaboration will take place [Turoff et al. 2009]. Planners of collaboration systems have to consider this: Appropriate tools might possibly be useful in supporting specific collaboration needs with previously unknown and unprepared actors in emergency situations. For example, with the help of mobile devices it might be possible to obtain a visual overview of the situation faster than with manual location reports alone or verbal situation information updates via radio.

The objective of this article is to examine mobile collaboration practices in crisis management on an interorganizational level. The research question is how emergent collaboration needs in the current work of interorganizational response teams, who are located on site as well as in the relevant control center, could be supported by cooperative information systems, especially mobile geo-collaboration systems. The notion of *emergence*, coined by Lewes [1875], refers to dynamic contexts that cannot be anticipated to their full extent before they actually occur. The article is organized as follows: Section 2 presents related work on mobile devices, geo-collaboration, and ad hoc participation in emergencies. Section 3 presents our overall research approach of *design case studies* [Wulf et al. 2011], which consist of a first empirical analysis of mobile collaboration practices in the field (Section 4), the development of innovative ICT artifacts related to the empirical findings (here, a mobile geo-collaboration system – Section 5) and the evaluation of their appropriation in practice (Section 6). Section 7 presents a discussion and outlines dimensions for the effects of our approach.

2. RELATED WORK

The cooperation of spatially and temporally distributed teams has always been a topic in the fields of computer-supported cooperative work (CSCW) and HCI [Johansen 1988]. Our CSCW and human–computer interaction (HCI)-related work stands between the areas of interorganizational crisis management, improvisation, mobile collaboration, ad hoc participation, as well as geographic information systems (GIS). In this section, we review the related work in these areas and outline the research gap that we would like to help close within the article.

The terms "disaster, crisis, catastrophe, and emergency management are sometimes used synonymously and sometimes with slight differences, by scholars and practitioners" [Hiltz et al. 2011]. An enormous effort regarding coordination, cooperation, and collaboration is essential for whatever form disasters, crises, or catastrophes take. Based on an analysis of the response work to the September 11, 2001 attack on the World Trade Center in Manhattan and the Pentagon in Washington, DC, Mendonça [2007] suggests that some frame specifics of emergency management can be considered as characteristics: (a) *Rarity* of incidences limits opportunities for training and learning. (b) *Time pressure* forces a convergence of planning and execution. (c) *Uncertainty* is present because the development of an extreme incident is rarely predictable. Furthermore, extreme events have (d) *high and broad consequences*, thus there is a need to manage interdependencies within a wide range of physical and social systems. The (e) *complexity* of the event arises, which is partly due to the high and broad consequences. Finally, (f) *multiple decision-makers* and responding organizations may

negotiate with each other, while responding to the event (see also McMaster and Baber [2012]). Based on interviews with emergency responders, Chen et al. [2008] describe similar characteristics but highlight also the "disruption of infrastructure support" as an important occurrence.

2.1. Information Exchange, Improvisation, and Ad Hoc Participation

Many situations require spontaneous, ad-hoc decisions and short-term (re-)planning, thus the provision of different information. Quarantelli [1988] identified five different categories of problems associated with information flow during disaster: (1) intraorganizational; (2) interorganizational; (3) from organizations to the public; (4) from the public to the organizations; and (5) within systems of organizations. Wenger et al. [1989] suggest that the "serious communication problems [regarding] both police and fire departments [. . .] stem less from lack of equipment or resources but primarily from the [. . .] pre-disaster planning with respect to information flow." However, the collapse of information flow and role systems need not necessarily result in a disaster if people develop skills in improvisation [Weick, 1993]. Besides consideration of social practices, the design of computer-based systems also needs to be informed by an understanding of the cognitive processes involved in responding to unanticipated contingencies [Mendonça 2007].

Suggestions for supporting improvisation in emergency management include graphical representations of data during crisis response; the centralization of data, making it possible for actors to find the necessary information; and virtually supported coordination in order to consistently create shared information in time [Adrot and Robey 2008]. Other approaches identified ad hoc replanning and the ability to share material as design challenges for large-scale events [Ley et al. 2012; Lindström and Pettersson 2010; Turoff et al. 2004, 2009]. Based on decades of research, Turoff et al. [2004] point out that "supplying the best possible up-to-date information is critical" and "crises involve the necessity for many hundreds of individuals from different organizations to be able to exchange information freely, delegate authority and conduct oversight, without the side effect of information overload." Information overload is also connected to information politics, as pointed out by Schmidt and Bannon [1992]. According to their view, a perfect collaboration does not necessarily emerge from a situation in which all information is available. McMaster and Baber [2012] share this understanding and suggest talking to colleagues instead of providing an overwhelming amount of information. Hiltz et al. [2011] argue that the field of HCI needs to "investigate further how to integrate both formal and informal sources of information" and "how systems can be designed to make such an integration efficient." Therefore the support of collaboration and communication instead of mere information sharing is a high priority. Nonetheless, the sharing of accurate and timely information is a necessary (if not sufficient) precursor to collaborative work of this kind.

Information sharing, operational awareness, communication readiness, adaptiveness, and coupledness have been identified as barriers for interoperability [Kwon et al. 2011]. Bertelsen and Bødker [2001] point out the need to support peripheral awareness not only with the coordination of activities within a control room, but also in distributed work. Infrastructural issues, which are also important in crisis, may limit the ability to share information: Semaan and Mark [2011] studied how Iraqi citizens used information and communications technology (ICT), especially mobile technologies, to overcome infrastructure breakdowns during the second Iraq war. They describe people spontaneously creating a "social infrastructure" with ICT with new arrangements, for example, equipping all family members with different mobile phone carriers, setting up neighborhood electrical generators, and switching among different technologies to find one that works.

2.2. Collaboration with Mobile Devices in Emergencies

A lot of research focuses on the use of ICT in crisis management, also in mobile contexts. Conception frameworks [Chen et al. 2008; Peng et al. 2007], based on empirical studies, determine which devices are appropriate for certain cooperation contexts in crisis management other than digital radio. Both deem tablet personal computers (PCs) and personal digital assistants (PDAs) as the most suitable in terms of mobility. Since the release of these frameworks, smartphones and tablets have become more popular and powerful, and combine the performance of PDAs with the multimedia support of mobile phones. Both smartphones and tablets meet the requirements of everyday use and are fundamental elements of CSCW technology for mobile workers [Tamaru et al. 2005]. Furthermore, they are used every day by the majority of people, which is important in order to create tools for spontaneous use based on these devices. The growing range of newer mobile technology such as long-term evolution (LTE, or 4G) creates new possibilities for transmitting large amounts of data.

Various approaches already focus on supporting cooperation with the help of mobile devices. The officers in charge are the information providers and consumers, whereas units on site are primarily information providers [Nilsson and Stølen 2010]. The officers in charge, either on site or in the control center, are mainly decision makers, whose decisions result in actions performed by the on-site units. However, there are "minor differences between emergency response units within and between countries with respect to formalized routines and command structure" [Rakea and Njå 2009]. Büscher and Mogensen [2007] present prototypes that allow command centers to capture on-site movements live as well as information about the situation that can be assessed in order to be able to construct a better situation overview without having to disturb on-site units through verbal communication. Bergstrand and Landgren [2011] analyzed the impact of live-incident videos in the control center and found that the videos greatly improved situation assessment in the control center. Due to the flow of communication from the bottom up, the on-site units provided information colored by their situation and perspective or due to previous radio transmission, which led to problems regarding prioritization. Landgren [2006] suggests that verbal communication should be made persistent, visible, and accessible in order to support accountability. Catarci et al. [2010] present a system in which each on-site unit uses a PDA, supervised by a process management system, that orchestrates the units and conducts external data services. The mobile devices are able to receive tasks and add comments to captured pictures and videos to share them and display them on a map application. Another approach dealing with prioritization problems comes from Ludwig et al. [2013]. Their semi-structured request-and-report system, based on the Android operating system, allows necessary on-site information to be generated by request and then illustrated on a map. The study shows that the accuracy of requests and reports can be improved by using an appropriate metadata structure in addition to creating multimedia-based information content. The use of maps is also the focus in Schöning et al. [2009]. They present a prototype that "combines standard mobile camera devices with printed maps to ensure a quick and reliable exchange of spatial information."

2.3. Geo-Collaboration and Crisis-Related Map Mashups

Map mashups are often the basis for both mobile and conventional collaboration systems in crisis management. Zlatanova and Fabbri [2009] show that "maps are largely used as background information for location awareness and decision making." They argue that time restriction and human perception are some of the major bottlenecks for working with complex models. Kraut et al. [2002] found that visual information in

shared spaces improves communication efficiency and increases the knowledge of the task structure and situation awareness, especially in complex problem solving. Liu and Palen [2010] surveyed 13 crisis-related mashups to derive high-level design directions. They include the use of temporal data to communicate different levels of knowledge granularity, learning from the past through the preservation of spatiotemporal information flows and the recognition of geographical vulnerabilities.

In terms of group work, "most spatial decisions using geographical information are done by teams, but existing geospatial information technologies [. . .] have been designed for use by individuals," according to Cai [2005]. His approach extends distributed GIS with collaborative functionalities and proposes a system architecture that integrates web service–based distributed computing paradigms. Accordingly, Schafer et al. [2007] present a software architecture that facilitates the development of geocollaboration solutions and reuses existing geospatial information models. They emphasize the community-oriented nature of emergency management. The prototype CIVIL [Convertino et al. 2011; Wu et al. 2013] is based on that architecture, and supports map-based decision-making. Wu et al. [2013] contribute in the "design research on a new collaborative system [CIVIL] for teams doing complex geo-spatial planning tasks" and suggest to "provide both personal (role-specific) and shared (team) maps and support information transfer between them." Based on an evaluation, their developed guidelines include (a) integrating map services that people are familiar with; (b) allowing users to add personal comments and drawings that overlay on maps; (c) providing both shared and private maps as well as supporting the transfer of information between them; (d) providing visualization tools to present information and help information analysis; (e) allowing platform-independent, distributed collaboration; and (f) developing architectures that allow delegation of noncritical information management tasks to online public services. The open-source tool Big Board, which can be used in the browser or as a mobile application, facilitates distributed synchronous collaboration by teleconferencing over maps to enable situational awareness. However, spontaneous integration of actors from other organizations is not supported. Furthermore, the study does not present a detailed user study [Heard et al. 2014]. Another mobile geo-collaborative application named MobileMap [Monares et al. 2011] was designed to help firefighters arrive faster at the emergency scene, to allow them to exchange digital information during emergency response processes and to reduce the need for radio communication. The paper points out that well-known solutions are sometimes not appropriate: for example, for the volunteer nature of some firefighting teams due to special device requirements or because prices are too high.

2.4. Research Gap

Mobile phones are important tools to enable the inclusion of new forces in an ad hoc manner into the process of situation assessment, because such devices are always ready and at hand. Many previously presented approaches provide findings relevant for our study. Wu et al. [2013] contribute to the "design research on a new collaborative system for teams doing complex geo-spatial planning tasks" roughly similar to our approach, but without considering ad hoc tasks in mobile contexts. Ludwig et al. [2013] studied mobile reporting practices in emergencies and contribute to approaches to support "articulation work with regard to the ad-hoc gathering of information," but do not focus on shared map mashups. Monares et al. [2011] also studied collaboration using mobile devices within a fire department, but as with Ludwig et al. [2013], they also do not consider an integration of new actors outside the own organization to situation assessment in an ad hoc manner. Other studies provide good approaches

(e.g., Convertino et al. [2011], Landgren [2006], and Zlatanova and Fabbri [2009]), but do not cover our question as a whole. The research on ICT, among mobile collaborative GIS, to foster ad hoc participation in interorganizational crisis management, considering the actual collaboration practices, and explicitly focusing on their real—not just intended—appropriation and the impact on collaborative practices therefore continues to provide important research opportunities.

3. RESEARCH APPROACH

Our objective is to examine mobile collaboration practices in crisis management on an interorganizational level. Our research question is how emergent collaboration needs in the current work of response teams, who are located on site and in the control center, could be supported by cooperative information systems. We therefore have to understand intra- and interorganizational collaboration, situation assessment, and the decision-making practices of all relevant stakeholders involved. We use the *design case studies* [Wulf et al. 2011] approach, which consists of an empirical analysis of the practices in the field, the development of innovative ICT artifacts related to the empirical findings, and the evaluation of their appropriation in practice. This research is inspired by Lewin's *action research* as "comparative research on the conditions and effects of various forms of social action and research leading to social action" that uses "a spiral of steps, each of which is composed of a circle of planning, action, and fact-finding about the result of the action" [Lewin 1958]. In our case, "planning" is the empirical analysis of the given practices, "action" is the design and use of suggested ICT artifacts, and the evaluation leads towards "fact-finding about the results of the action. This interpretation is consistent with Hevner and Chatterjee's suggestion [2010] of integrating action research with design research. A *design science approach*, comprised of the design of an artifact for a relevant problem combined with rigorous evaluation methods for the design, is used to create the artifacts [Hevner et al. 2004].

These methods have been applied to study collaboration, situation assessment, and decision-making practices during coping and recovery work in emergency response agencies. Our research focus is on improvised collaboration between statutory and unanticipated actors in multiagency emergency response. The study was conducted in two regions in Germany in the years 2010 through 2013. County A is a densely wooded, hilly and rural county, whereas County B consists of 10 expanding urban communes. In both regions, we focused on several affected organizations: the infrastructure supplier (energy network operator [ENO]), public strategic administration (crisis management group, operations management), public operative administration (e.g., police, fire department), and citizens. The fire departments are organized differently in the two counties: County B provides professionals, whereas the fire departments of County A consist mostly of volunteer forces and only members of the control center have salaried positions.

According to our research approach, we will now first present the findings of our empirical study on mobile geo-collaboration (Section 4) and then the development of a mobile geo-collaboration system related to the empirical findings (Section 5). Finally, we will present our evaluation (Section 6) and implications (Section 7).

4. EMPIRICAL STUDY: MOBILE GEO-COLLABORATION IN CRISIS MANAGEMENT

4.1. Methodology

The bases for the data analysis were the results of multiple empirical studies from 2010 to 2012. The studies were embedded in a scenario framework describing a storm with many minor and connected incidents and energy breakdowns, which had been developed together with actors from the police and fire departments, county administration

Table I. Group Discussions (2010)

No.	County	Topic	Roles
W1	Both	Challenges in practice, control center visit	Energy Network Operator (ENO)
W2	B	Challenges in practice, control center visit	County Administration, Police Department, Fire Department
W3	A	Challenges in practice, control center visit	Department Head: Public Safety, Head of Civil Protection, Head of Police Control Center, Deputy Head of Control Center, District Fire Chief
W4	A	Analysis of user interactions and communication flows	Head of Police Control Center, Head of Staff Coordination, Deputy Head of Control Center, Local Head of Federal Agency of Technical Relief (THW), Local Head of German Red Cross
W5	B	Analysis of user interactions and communication flows	Head of Regulatory Authority, District Fire Chief, Red Cross: Disaster Management, Red Cross: Communications, Members of other aid agencies

and an ENO. The purpose of the scenario was to be able to create a common understanding of an occurring emergency quickly, therefore it helped to increase validity and comparability in our interviews. First we conducted observations in order to acquire knowledge about practical work in interorganizational crisis management. The observations were conducted in a control center during a normal working day (observation time: 9 hours), in the crisis management group and the operations management during a crisis communication training (4 hours) as well as at a major cultural event with about 400,000 visitors (6 hours). In addition to observations, we conducted 5 interorganizational group discussions (each 4 hours, with each containing about 10 participants) to understand the communication practices of interorganizational crisis management (Table I).

Furthermore, we conducted 22 individual interviews with actors from the participating organizations. Each interview lasted between 1 and 2 hours and followed an outline that was separated into three parts. The first part focused on the participants' role, qualification, tasks, and work activities under normal conditions. The second part covered the participants' tasks during emergencies in our developed scenario framework. The third part covered applied information and communication systems and perceived problems with these tools (Table II). Group discussions and interviews were audio-recorded and later transcribed for subsequent data analysis. The analysis of the data was based on the inductive approach found in *grounded theory* approach [Strauss 1987]. We chose this systematic methodology to discover insights about the work practices through the analysis of data. To be able to use this methodology, the transcripts were coded openly and the statements of the agents were divided into text modules, then later into categories. The knowledge previously acquired in the literature study was used to heighten *theoretical sensitivity* [Strauss 1987]. A part of the grounded theory approach is *theoretical sampling*, which means that the selection of the studied units is led by the conceptual structure or theory that emerges during the analysis. One result of the first phase was that the particular collaboration between the police force and the fire service, based on situation maps, is necessary in order to make appropriate decisions. Both have different management structures: in the police force the operations are led from the control center ("*from behind*"), while the person in charge in the fire department is the officer in charge, who is on site ("*from the front*"), and the control center only has a supportive function. To study mobile collaboration practices more closely, also in regards to the creation, exchange, and use of information by the response teams and the control center, an additional 5, partially structured, interviews were conducted (each 1 hour; Table II).

Table II. Interviews on Collaboration Practices (2010–2012)

No.	County	Organization	Role
I01	A	Administration	Regulatory Authority
I02	A	Police Department	Head of Control Center
I03	A	Police Department	Head of Section
I04	A	Police Department	Patrol Duty
I05	A	Fire Department	District Fire Chief
I06	A	Fire Department	Deputy Head of Control Center
I07	A	Fire Department	Workforce
I24	A	Fire Department	Head of Control Center
I08	B	Administration	Office of Civil Protection
I09	B	Fire Department	Chief Officer/Chief of Fire Department
I10	B	Fire Department	Operation Controllers
I11	B	Fire Department	Clerical Grade Watch Department
I12	B	Fire Department	Control Center Dispatcher
I13	B	Fire Department	Head of Control Center
I14	Both	Police Department	Member of the Permanent Staff
I15	B	Police Department	Head of Control Center
I16	B	Police Department	Head of Group
I18	Both	ENO	Higher Area, High Voltage
I19	Both	ENO	Operation Engineer, High Voltage
I20	Both	ENO	Operation Technician, Low Voltage
I21	Both	ENO	Dispatcher, Low Voltage
I22	Both	ENO	Workforce, Technical Incidents
IM1	A	Police Department	Head of Control Center
IM2	A	Fire Department	Control Center Data Support/Digital Radio
IM3	A	Fire Department	Administrator of Control Center
IM4	A	Police Department	Head of Police Station
IM5	B	Fire Department	Department Chief of Control Center

4.2. Results: Informal Work and Mobile Ad Hoc Participation

In this section, we show the correlation and necessity of informal work and mobile ad hoc practices in crisis management. We first show the need for improvisation and informal communication in order to respond to the high dynamics of an emergency. Informal communication predominantly takes place via mobile devices. This 1:1 communication channel by mobile devices lacks the situational awareness of the other units, especially on site. The current technologies of the different organizations address neither the direct cooperation with other organizations nor the cooperation with the unsalaried voluntary forces in a satisfactory and efficient way. Statements and quotes in this section are attributed to the sources from the interviews listed in Table II, indicated in the parentheses by interview number from that table.

4.2.1. Unforeseen Situations and Complexity Requires Informal Communication. Due to the high complexity and unpredictability of an emergency, improvisation and variable ways of working are necessary. Different, often unexpected, organizations have to be contacted spontaneously, for example, the residents' registration office for checking on the residents of a house, or the water protection authority for checking the consequences of a flood in an industrial area.

"It has to be like this, because no two situations are alike. I think that is the big advantage we have over other services [. . .] Because fundamentally the firefighters and us [police], we work differently compared to the other administrations [. . .] Otherwise we would just be helpless" (I02).

The actors involved know that the capability to spontaneously integrate unexpected but required organizations is a big advantage in their work practice. However, emerging situations and spontaneously involved organizations, as well as frequent bypassing of process structures that were previously defined by the emergency services, require a high level of informal communication. Current ICT systems, however, do not support the mapping of such involved actors onto the predefined and digitally represented work structures and plans. Informal communication and contacts are therefore important both when addressing organizations and their respective units directly as well as for being able to work interorganizationally in a trusted environment (I02). In a trusted environment, all organizations are willing to share the needed internal information, except for critical and crime-related data in the operations of the police (IM2). Information like road barriers or collecting points and all other information in noncrime-related operations can be provided and shared, also by the police. It is a common practice when trying to obtain relevant information. Phones and mobile phones are the primary work equipment (I08), followed by e-mail and radio (I02) during such interorganizational informal practices. Even if such communication channels are needed, caused by the complexity of the situation, the units are aware of the discrepancy with regulations and legal agreements:

> *"There are a lot of different ways to get information and they are not always in accordance with the law." (I05)*

> *"This type of verbal communication is not being accepted as evidence. That's why someone has to run after him [the section leader] all the time and record everything with a voice recorder and write it down." (I09)*

Communication through mobile phones is fast and easily facilitated, but the traceability of the conversations is often hard to establish. Digital radio is currently just being introduced; therefore 1:1 communication via radio has not been possible. The current practice therefore is that people with recorders have to follow the decision makers on site as well as in the control rooms. Thus extra work is caused by the fact of the ad hoc, direct as well as informal—but required—communication mechanisms.

4.2.2. Informal Communication Enables Ad Hoc Participation but Lacks Awareness. It is obvious that informal communication through mobile phones enables ad hoc involvement of individual actors during an emergency (I02). Such flexible communication is especially used during the arrival phase of emergency forces on-site:

> *"The usual way is to brief you on the go [to the incident place] using a mobile phone: What is going on? Thereby you get a rough idea. This form of communication is, of course, more work for the supervisor to brief each unit individually, but that is because we just do not want to wait so long." (I04)*

Using flexible ad hoc participation through mobile phones for briefing units on the go and units arriving later individually during the drive to the incident location has an enormous advantage of speed. This saving of time enables the units to act directly after arriving on site, which leads to immediate care of injured persons or responding to an emergency in accordance with the overall operation. Although this is a major advantage, the individual briefing via mobile phone has one important drawback:

> *"The use of mobile phones makes it harder to notice a situation than through analog radio. In the past, when everything was transmitted by radio, it was not a problem, because everyone could hear everything, but today, because of our poor 2-meter analog radios, mobile phone technology is being used more and more." (I02)*

Such a *"living-in-a-situation"* (as frequently mentioned by the participants), which is absolutely necessary for getting the big picture, is no longer possible due to the frequent (but required) fallback on mobile phones (I02). In the past, the decision-makers often assessed a situation only by getting information from an on-site leader who perceived the communication between on-site units through radio. While it is hard to get an appropriate overview of the situation through radio, it is much harder to get an overview through mobile phones:

"We see again and again that the off-site control center has a completely different picture of the situation than the on-site units." (IM01)

The 1:1 communication channel, without awareness of the activities of other units and their surroundings through the radio, sometimes leads to misunderstandings between the on-site units and the control centers. For getting a better overview of an environment, another current practice of on-site units is obtaining the necessary additional information on the environment with someone's smartphone:

"Some colleagues have Internet access on their smartphones, which is often helpful for looking at a location on Google Maps using the satellite view." (I04)

By taking a look at the maps, they coordinate actions for searching sections or blocking roads. The participants mentioned that currently it is not possible to integrate additional information such as important buildings to the map as they are used to being able to do with their physical situation map. They argue that there should be an option to integrate different external information, such as weather overlays, on the map that is already used on site:

"There's a cloud of smoke and then you can have a look. [. . .] The cloud will be there and in this layer and that area is endangered." (IM3)

By seeing the situation on site (e.g., the fire and its cloud of smoke) and external integrated information (e.g., wind directions) the units can calculate the temporal progress of the emergency and its further implications. But to establish an overall appropriated situational awareness, the units asked for the integration of internal operation-related information *produced by them*, such as collecting points, to the already used on-site smartphone's map:

"It would make sense, if I had the possibility to add a text field on the map that lets you add a radio name or something like that" (IM1) and "that we can draw in areas [e.g., road barriers or collecting points] on our own." (IM4) "To avoid any discrepancies, the most important thing is that it [the on-site map] has to be 100% in sync with the situation map at the control center." (IM5)

The units are aware that the already existing information gap between the on-site units and control center could get even bigger using technology that could get out of sync. Transmission techniques are therefore needed that are always available. The units have years of positive experience with using standards built on the Global System for Mobile Communications (GSM) network. There are, however, a few negative experiences, such as what the participants call the "New Year's Eve Effect," in which the GSM-network is temporarily overloaded:

"It would be best if it [information] could be transferred via WLAN or UMTS, then the control center could also look at it. That way, the overlap [same understanding of the situation] between the officer in charge on site and the control team would be

bigger. Otherwise, someone is talking about a fire here and the others think he is talking about a fire somewhere else." (IM2).

4.2.3. Lack of Technical Support Precludes Involvement of Volunteer Forces. The professional forces have, apart from radio, no dedicated technical means to involve the organized volunteer forces, such as the volunteer fire departments or aid agencies, in coping and response work. Especially in Germany, volunteer forces are an important part of the nonpolice emergency services, but are not really integrated into the existing IT infrastructures and dedicated information systems. The problems start already during the alarm process:

"Unfortunately, the sirens have been gotten rid of, which is very bad." (I07)

In Germany, there are no more sirens at the fire stations to alert the volunteer forces. This is mainly due to the noise level. Following the abolition of the sirens, the only way to alert the volunteer firefighters is by silent alarm via pagers. The addressing of volunteer firefighters through pagers is seen as very critical:

"You cannot force them to use their pager. If someone is sweeping his garage or is in the garden and has his pager in the house, he does not notice the alerts." (I07)

Besides the alert itself, the response to such an alerting is often a problem, because the pager has no feedback functionality to the professional services. The professional alerts the volunteer fire stations without knowing the availability of the overall units and must wait until the leader of the volunteer services gives an official status:

"I will alert my volunteer fire department. But I never know how many will come, because there is no roster." (I09)

For this reason, they have to be re-called via mobile phone, although phones are currently not part of the official alerting and response procedures. After a successful alert, several further communication problems exist due to the multiplicity of systems between professional and voluntary forces:

"In the volunteer fire department, there aren't often really computer-savvy people [. . .] It needs to be easy for them." (IM2)

Users of current systems often need very extensive instructions and are therefore not suitable for volunteer units who do not use them on a daily basis. But these forces still play an important role in major incidents (I05). Usually, the volunteer forces operate in local areas, dealing with very small incidents such as small fires. They are neither using, nor familiar, with the professional IT-systems. Intuitive systems are therefore required, which are made for the "IT dyslexic" (I02). The units are not trained on the systems that should be used during emergencies (I06). Due to these problems, the units fall back to mobile phones (I07).

4.2.4. Missing Situational Awareness through the Phone Handicaps Liaison Officers. Problems exist beyond the single organization or organization type. Interorganizational coordination (crisis management group and operations management) usually takes place via so-called liaison officers. Liaison officers have an extensive knowledge of the working practices and current processes of their own organization (I14). They sit at the control centers of the other involved organizations and are connected to their own organization by mobile phones, which have access to the Intranet of their respective organization (I14). Since a connection to a control center exists for their liaison officers only and not necessarily to the crisis management systems of the other organizations, the liaison

officers must be able to decide what information needs to be answered and transferred to their control center immediately and what can be assigned a lower priority:

> *"It is very difficult because the handling of information can vary in different situations. [. . .] You have to think again and again of how information can get from one organization to the other." (I14)*

Liaison officers have to decide very quickly who of their organization needs what information when and how must it be delivered. On the other hand, they have to decide what information from their own organization must be transmitted to the organization they are currently working with. This decision process is framed both by law (legal agreements) and human cognitive skills.

> *"I need reliable information for a decision in a specific situation [and] the most secure information is the information which I have seen myself." (I05)*

Liaison officers have the problem "that we cannot look through the phone. We cannot see what it looks like on-site" (I06) and must rely solely on verbal language. The head of the police control center stated: "If you visualize the firefighters' position, as well as their capacity, that would be helpful for all" (I02). All interorganizational information that is to be exchanged has a geographical reference: "We are interested in position spaces, operation spaces and many other things such as danger areas, operation volume or escape routes" (I15). It is, that is, desirable to get the "big picture" of the situation (I15). By automatically providing and displaying information with geographical references, liaison officers would be significantly aided and the overall process would be much more efficient.

4.3. Summary

The rigid and predefined emergency services process structures cannot address the complexity and unpredictability of an emergency, as a high level of informal communication and improvisation is required. For these informal communication practices, mobile phones are the primary work equipment, especially when dealing with volunteer forces or when cooperating on an interorganizational level through liaison officers. Informal communication techniques enable the ad hoc involvement of individual actors during an emergency, but provide for little awareness and make it more difficult to be aware of a situation than through the use of radio. "Living in a situation" (an expression always mentioned by the participants), which is absolutely necessary to get an overview of an event, is no longer possible due to the frequent fallbacks to the 1:1 connection through mobile phone use. When a unit participates in an ad hoc manner, the on-site units use a workaround with existing maps on their smartphones to get a better overview and enhance the communication with visualization options. Using only those maps cannot fulfill all the requirements such as annotations or map sharing. But these options support the informal mobile phone calls and pave the way for the fast involvement of the units in the coping and recovery work.

5. CONCEPT: MOBILE GEO-COLLABORATION SYSTEM

To research informal and spontaneous participation practices as well as possible cooperation mechanisms technically, we decided to develop the application *MoCo* (*Mo*bile *Co*llaboration app) taking the results of our empirical study into consideration. Addressing the empirical findings, the system tries to assist unforeseen situations by supporting informal communication and explicitly trying to maintain a high level of awareness while enabling ad hoc participation and visualization of the situation. MoCo is based on the existing GIS *ISAC* (*I*nterorganizational *S*ituation *A*ssessment *C*lient)

Fig. 1. Screenshot of the mobile geo-collaboration system MoCo on tablet (A), the information pool to manage and select information resources (B), and the administration of the collaboration mode (C).

[Ley et al. 2012, 2014], which is adapted for mobile devices and extended to special mobile needs [Reuter and Ritzkatis 2013]. We decided to develop a smartphone-based application because smartphones are widely distributed even among volunteer forces and are used for visualization in addition to calls; furthermore, units are already skilled in private life to use these devices. Since private smartphones are already present, tablets could also be used in the future in emergency work. We therefore designed a native Android app to address both device classes.

In Figure 1(B) the user has the option to slide in functionality to display a mobile version of an information repository for integrating external and internal information [Ley et al. 2013]. The information repository is structured through different main categories such as weather, traffic, important locations, or private information. To avoid information overload on the map, such information can be shown individually or hidden, or collected in different map layers. For example, during a flood emergency, only information such as water levels and past flood areas need be presented; during the evacuation of a hospital only local hospitals or shelters are presented. External information, such as weather information provided by the meteorological service or blackout areas provided by the ENO, can be integrated in two ways: it is possible to insert a URL for an OGC[1] specified Web Map Service (WMS) to use geo-referenced map images from the Internet that are generated by a map server using data from a GIS database. The data exchange is implemented according to the DIN SPEC 91287:2012–07 on "data interchange between information systems in civil hazard prevention." The second way is to add a Keyhole Markup Language (KML) layer, an XML notation for expressing geographic annotation and visualization within Internet-based maps.

Internal information can be added manually on the map by clicking onto or searching for a location, assigning information to a specific category (e.g., police unit or fire department) and giving the insertions a short description. The description will pop up

[1]The Open Geospatial Consortium (OGC) is an international industry association for developing publicly available interface standards.

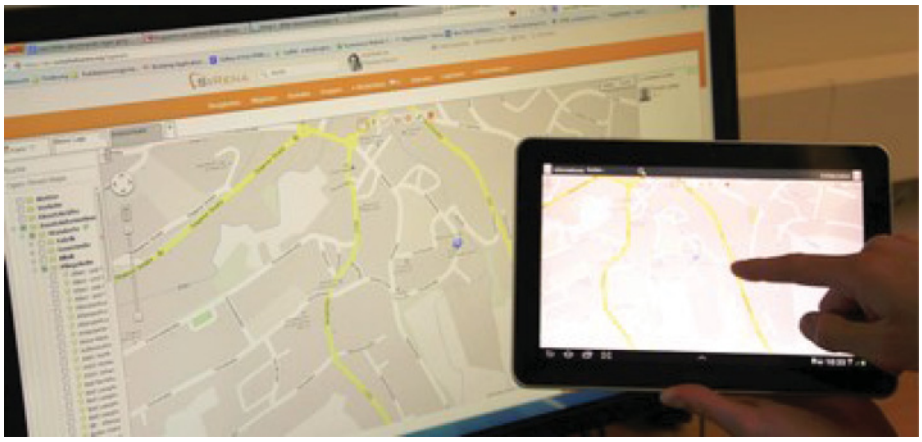

Fig. 2. Collaboration mode in the browser and on tablet.

when the information marker is tapped. Additional annotations (Figure 1(A)—such as circles, polygons, or hand-drawn sketches—can be inserted to mark special, mainly temporarily, locations or situations: for example, road blocks or collecting-points during operations. These annotations are declared as private objects that allow the user to make personal drawings or short marks in addition to the general shared information on the left side.

The idea of a mobile, map-based visualization support for on-site units and an application like this one is not novel and has been studied in the past (see Section 2.2, e.g., Büscher and Mogensen [2007], Monares et al. [2011], Wu et al. [2013]), but here it is used as the basis for the innovative main functionality called *collaboration mode*, which can be displayed at the right side (Figure 1(C)). Collaboration mode allows the user to make changes on the current map. The user has the option to easily invite someone spontaneously into his collaboration session to see the same view and all changes on the map synchronically using the smartphone application or the browser version. It implements the principle "What You See Is What I See (WYSIWIS)." When starting collaboration mode, a dialog appears showing a list of the participants that are registered in a related interorganizational crisis management system, which can easily be extended to involve other participants. The creator of the session (manager) can invite as many users (participants) as needed to discuss a situation in a dispersed manner. This enables the manager to address several units in an ad hoc and dynamical way: also interorganizationally, including on- or off-site units using our smartphone application or a modern web browser. When the invitations have been accepted, only the manager has write access. At the same time, the manager has the option to assign these rights to someone else and can regain them forcibly. This restriction ensures that the map will not become overloaded and that everyone pays attention to the discussed information. In addition to mobile phone calls, collaboration mode offers a multilateral communication environment instead of bilateral calls and visualization should overcome verbal limitations, especially when talking about geo-referenced information, giving the user more tools for expression. Every annotation that represents, for example, a collection point, road barrier, or some other point of interest can be shared with all participants of the collaboration session and can thus enhance awareness. Collaboration mode offers the option of enhancing mobile calls so that more than one person and distributed units can participate in the process of situation assessment. It also creates a shared view of the geo-spatial representation of a situation (Figure 2).

Table III. Participant Evaluation, First Iteration (2011)

No.	County	Organization	Role
E01	A	Police Department	Head of Control Center
E02	A	Police Department	Head of Section
E03	A	Fire Department	Deputy Head of Control Center
E04	A	Department	Head of Control Center
E05	Both	ENO	Operation Engineer, High Voltage
E06	Both	ENO	Operation Technician, Low Voltage
E07	Both	ENO	Higher Area, High Voltage
E08	B	Police Department	Head of Control Center
E09	B	Police Department	Head of Group
E10	B	Fire Department	Head of Control Center
E11	B	Fire Department	Watch Department
E12	B	Fire Department	Head of Group

Collaboration mode can only be used with the support of web sockets, a web technology providing full-duplex communication channels over a single TCP connection. Web sockets have been available in web browsers since mid-2011. Currently, a secure and established version of the web socket protocol is implemented in Mozilla Firefox 6, Google Chrome 14, and Internet Explorer 10. In a mobile context, the connection between mobile clients and the server is a special challenge. Taking this into consideration, instead of transferring complex objects, an exchange of chains of symbols was made possible, so that an entire marker object is not sent, only the features of the marker (location, name, and so forth). The marker object is recreated in the receiver application. This minimizes the data transfer amount. Furthermore, the collaboration server is not established on the device of the inviting actor due to the possibility of losing the Internet connection.

6. EVALUATION

6.1. Methodology

In order to evaluate the empirical findings, requirements, and our supportive tool allowing ad hoc participation, we evaluated the prototype with 33 different users. The first development cycle led to a web-based situation assessment prototype, which was evaluated in an interim evaluation using scenario-based walkthroughs. First the prototype and its functionality were briefly introduced, then the participants had to use the application and solve predefined tasks. The subsequent interview covered: first impressions; system handling; conceivable use cases; requirements to make the system usable; collaborative situation assessment; and further information needs (Table III).

The second cycle extended the prototype to an interorganizational geo-collaboration system and was evaluated under real-use conditions. For this evaluation, we rolled out the prototype for a limited amount of users and after a 3- to 5-week evaluation period, we conducted interviews with 16 of the participating users on usability, the integration into working practices., and interorganizational issues (Table IV).

While those evaluations focused on the whole concept, additional evaluations were performed that focused on the realized Android application, allowing mobile ad hoc information exchange and collaboration (Table V). During these evaluations, collaboration mode was demonstrated using both mobile devices and the browser version (Figure 4). Each evaluation lasted on average about 60 minutes.

Each interview session was audio-recorded and transcribed for subsequent analysis, which was divided into three steps [Schmidt 2004]: (1) The transcripts were structured according to the questions of the interview guideline. Statements taken from

Table IV. Participant Evaluation, Second Iteration (2013)

No	County	Organization	Role
E13	A	Red Cross	County Head
E14	A	Fire Department	Administrator, Control Center
E15	A	Fire Department	Staff of Control Center
E16	A	Fire Department	Head of Fire Department
E17	A	Police Department	Head of Section
E18	A	Police Department	Staff of Control Center
E19	A	Police Department	Staff of Control Center
E20	A	Police Department	Staff of Control Center
E21	A	Police Department	Head of Control Center
E22	Both	ENO	Operation Engineer, High Voltage
E23	Both	ENO	Operation Engineer, High Voltage
E24	B	Police Department	Staff of Control Center
E25	B	Police Department	Data Administration, Control Center
E26	B	Police Department	Staff of Control Center
E27	B	Fire Department	Workforce
E28	B	Fire Department	Staff of Control Center

Table V. Participant Evaluation of Mobile Applications (2012)

No	County	Organization	Role
EM06	A	Police Department	Head of Control Center
EM07	A	Police Department	Head of Section
EM08	A	Police Department	Head of Section
EM09	A	Police Department	Executive Staff
EM10	A	Police Department	Executive Staff
EM11	A	Fire Department	Fire Chief, Administration Control Center
EM12	A	Fire Department	Municipal Fire Inspector
EM13	A	Fire Department	Volunteer Fire Chief
EM14	A	Fire Department	Volunteer Workforce
EM15	A	Fire Department	Volunteer Workforce
EM16	A	Fire Department	Volunteer Workforce

the transcripts shed light on participants' reactions during the session. (2) Based on the transcripts, ex-post categories were formed for the analysis. This categorization included aspects about the implementation and integration of the system with existing infrastructures and practices, cases for the application of this approach, and recommendations for improvements. (3) These analytical categories were used to create a coding guideline. It helped to cluster the data in terms of meaningful units to focus on specific problems.

6.2. Results: "Include People that were Previously Left Out"

Using our design, we were able to derive the impact of mobile collaboration infrastructure on the improvisation practices of decision-makers and on-site units. First, we saw that the prototype allowed the configuration of an individual set of information that was used for personal information retrieval, employing various pieces of information from the Internet:

"It is perfectly aimed at all those things where everyone has his own list of favorites. You can put it together as you need it" (E23–13:53) or: "it is all in one" (E26–9:15).

The configuration of this "own list of favorites" is crucial because even in the structured work of the control center, which is also shaped by legal requirements, individual dispatcher work is different and also uses diverse information. The empirical study had illustrated that the piece of information that is needed to make a decision varies from situation to situation as well as individual to individual (I03) and our evaluation confirmed it. It was observed that MoCo has the potential to enrich information assessment by obtaining and seeing information from other organizations in a timely fashion:

"Interconnectedness would be interesting for us [. . .]. Then we could invite the fire service or other organizations to this map. The fire service will certainly—not immediately—check where the police are stationed. But at some point you're going to check what others are doing." (E24-18:00)

The information from other organizations could have direct impact on one's own operations and measures. Currently, those processes of coordination take place via verbal communication channels only, often through mobile phones. Functionality for collaborative sense-making and its interoperability is therefore an important requirement:

"We have quickly created a common picture. And in the end, we can only operate successfully if we work together with the fire service, the Maltese ambulance service, and the Red Cross. [. . .] I could make a map for my fire service colleagues, and shade parts in order to tell them that they don't have to worry about that area." (E13-41:40)

A special emphasis in the evaluation was put on the demonstration of the exchange of information. Especially when information is being exchanged during an emergency case, the interviewees saw an improvement with regard to their current work practices.

"In the executive staff group, I also need other information: when I work with actors from several sections, I can set the section maps and they are automatically updated by the section leaders." (EM06-8:19)

By providing a technical solution like MoCo, the head of a section can work as a supplier of information and in the control center the information automatically comes together. The function "send me the map of what we have done so far" (EM07) was rated especially positively. The most important issue concerning the changes of working practices was the possibility to "include people into situation illustration that were previously left out" (E16-25:44). The interviewees elaborated that currently it is possible to talk to each other or to send photos from phone to phone in 1:1 communication, but not to actively and easily collaborate and exchange information independently of the existing infrastructures. For such collaboration, several cases for ad hoc participation were observed by us and mentioned by different actors during our evaluation sessions. They will be described in the following.

6.2.1. Control Center and On-Site Units' Coordination. The first case to include people that were previously left out focuses on the cooperation of spatially distributed services of the control center and units on site (Figure 4):

"Mainly, we do not work in the control center, we work on-site. [. . .] We do internal things for ourselves and the incident command does it on site. It would be good if we were always at the same information level as the command vehicle." (E28-20:22)

Or: "For purposes of coordination, you should be able to see the same on site as in the control center." (E01-37:10)

Fig. 3. Evaluation of MoCo on smartphones, tablets, and laptops in a fire department (2012).

Fig. 4. Evaluation: using radio and MoCo on-site (left) and the web browser version in the control center (right) (2013).

On-site units often have to make decisions in real time. Much information from other involved professional organizations or from citizens arrives at the control centers. But the transmission of information lacks speed as well as widespread distribution across all on-site units. Synchrony would therefore be especially important during the aforementioned kind of cooperation: "A synchronous display of information is useful, exemplary especially for discussions on whether we should block this or that road" (E02). For such situations, the use of the smartphone version of our system was recommended:

> *"You should certainly use something like that on a tablet PC or a notebook when the colleagues are on site. Here, for instance, you could add regions for a search for missing persons. The on-site forces could be divided based on this information." (E20-50:41)*

Such cooperation could in some ways replace or enhance the already established phone calls by reducing the disadvantage of 1:1 communication and lack of situational awareness of the other actors:

> *"We get information from the fire service when, for example, there is a fire somewhere [. . .]. [Using an] App for the smartphone, we could just add the disturbance instead of taking a call from someone; we could just directly add it to the map" (E22-19:15).*

Concerning the addition of information directly to the map, the transmission of coordinates was also mentioned in order to support cooperation between the control center and the on-site units:

> *"Especially there are often areas that don't have a name or number, but are somewhere in the open field. In this case, I can also imagine that, rather than discussing it for a long time, you could add a marker and share it." (E23-26:30)*

By using an application that supports map-based visualizations, the error-prone discussions about locations (e.g., correct street, but wrong city) can be prevented, or at least reduced.

6.2.2. Including New Forces from Other Organizations or Regions. A second case for lightweight tools for sharing digital representations ad hoc is cooperation among organizations, for example, with new forces from other regions, which is necessary especially in more severe situations and which is closely connected to the issue of discussions about location:

"I could provide an on-site overview. For instance, some people from Burbach [another city] arrive, who know where our city is, of course, but do not know where the Bismarckstraße [street] is." (E13-32:19)

The new forces from other regions do not have the technology to figure out what location is meant and how they reach it. This time-saving feature can enhance access routes to the incident's location. Another example mentioned was coordination with other units, such as rescue dog forces, which are usually not part of the core crisis management team but have to be consulted in special cases, for example, missing persons. Such cooperation support could improve the possibility of appointing other organizations to tasks via the control center:

"You could implement the entire situation and create search maps. The rescue dogs are the ones who need the most map material because they run crisscross." (E13-21:24)

"We must organize or inform them in such a way that they do not work too autonomously. We always have problems like that." (E15-40:36)

The map could therefore act as an "educational object" (E16-41:14), in which the locations of the forces are displayed in order to answer important questions, including: Where exactly are the on-site forces? What are they doing? Where are the other forces located? (E02, E09). Obtaining the answers are a top priority, mainly for the police, whose head of operation "leads from behind" and does not have contact with each unit. Besides the allocating and distributing of units, information sharing is important in such scenarios. The interviews emphasized that basically there were no concerns about sharing information with others, neither from the police nor the fire department, nor any other involved organization: sharing in such scenarios is essential.

"During a major situation, we have to exchange information. In this case, we dispatch a liaison officer to them [fire department] and they send one to us. From then on, there are no more secrets anyway." (E24)

"Depending on the category of information, it could be shared automatically." (E01-39:30)

However, especially on the police side, there is confidential information that has to be kept secure. This kind of information would not be shared, neither via our application nor via phone or by radio:

"For example, during a violent demonstration we also work together with fire department and ambulance services. But there is tactical information on the police side that will not get to the outside. [. . .] Every operation where special forces are involved." (E21)

6.2.3. Collaboration outside the Office/Office Hours. The third case of emerging cooperation scenarios affects collaboration scenarios outside of office hours. Actors are usually equipped with technology only in their office and during their office hours. Using mobile phones with collaborative applications, it would be easier to include actors that are currently off duty in the process of situation assessment:

> *"Disturbances do not just happen during office hours but also, for example, on a Saturday night, and in that case it would be useful [. . .] (A) Maybe some data is already in the system, blackout areas and so on. And (B) I could show something by marking it and saying: 'Here we have this and that problem'. Then I could [. . .] upload pictures, or other material I've got relating to an object to make the situation more transparent, because today we do all that via telephone. Sometimes with difficulties." (E23-24:00)*

An emergency can arise at any time. The units at the control centers as well as on-site therefore are often changed while responding to the emergency. An application like MoCo supports the handover during a shift change, because instead of reading all the reports, the forces take a look at the digital map, even while arriving either at the control center or on-site:

> *"Such visualization is helpful for shift changes. It is much better than thrusting a stack of paper in someone's hand, with information about the whole procedure" (E21).*

6.2.4. Perspective Outlook: Sharing with the Public. The possibility of also sharing the physical situation map in digital media leads to further opportunities:

> *"Someday we should have the option to publish a map we have created. Where the citizens can look and check what the matter is: this street is blocked and that street is blocked." (E16-42:03)*

Professional organizations sometimes have significant problems reaching the wider population living in the affected area or those who might be interested in the emergency (e.g., family members). By providing a digital version of a situation map, it is possible to share it (or parts of it) with concerned citizens. The existing functionality should therefore be enhanced:

> *"If I draw a circle around an incident location and annotate: 'Close the doors and windows,' as public information." (E16-44:10)*

A large-scale telecommunication network breakdown that occurred in the capital city of County A led to breakdowns of the landline service, emergency numbers, control center websites, and local radio. In this case, the Facebook website of the control center was used for citizen communication and information was published by the authorities. The interviewees mentioned that if they had functionality for providing geographical information, as is possible with MoCo, it would be much easier to inform the citizens in an appropriate way.

6.3. Limitations

Such digital representations have limits. Many interviewees mentioned that they are best suited for longer emergencies, as a police representative said:

> *"For situations in which we have offenders on site, it is not suitable. It's too clumsy; how we work now is better. It is different for situations that develop over several days, such as a fire or a flood. It is a great tool for that." (E17-37:07)*

Furthermore, large-area emergencies were mentioned as a limitation. Other limitations are that the devices have to be available (E02). At present, that is often the case—even for volunteers—because MoCo works on normal smartphones as an Android application or browser version, which is now widespread and will increase in the next few years. Furthermore, the quality of the network infrastructure was mentioned, which is sometimes poor, especially in rural areas, and might break down during heavy storms (E02). Priority circuits could help those who are especially dependent on phones to use the mobile network efficiently. In some evaluations, it also became clear that there is no specific experience about aspects dealing with access control. Current practices with a single situation map in the control center restrict access based on physical presence in the control room. While using digital representations, which can be shared among the users, new possibilities and questions will arise (E16), including, for instance, role-based access restrictions, free access for all emergency services, or explicit sharing of information.

7. DISCUSSION AND CONCLUSION

The collaboration between the units of all organizations involved in crisis management is generally shaped by legal regulations (e.g., regarding notification and documentation duties) and professional conventions (e.g., liaison officers). However, in a crisis, the rigid and predefined emergency services process structures connected with these regulations and conventions often cannot address the complexity of a situation [Palen and Liu 2007]. Supporting improvisation is, in our eyes, one of the crucial strategies. There has been previous research on the technical support for the cooperation of emergency services on site, for example, on the basis of mobile map-based applications (e.g., Bergstrand and Landgren [2011], Büscher and Mogensen [2007], Catarci et al. [2010], Ludwig et al. [2013], Monares et al. [2011], and Nilsson and Stølen [2010]), on different aspects of geo-collaboration (e.g., Cai [2005], Convertino et al. [2011], Liu and Palen [2010], Schafer et al. [2007], Wu et al. [2013], and Zlatanova and Fabbri [2009]), information visualization and sharing (e.g., Hiltz et al. [2011], Quarantelli [1988], Turoff et al. [2004], and Wenger et al. [1989]), as well as on improvisation during emergencies (e.g., Adrot and Robey [2008], Ley et al. [2012], Lindström and Pettersson [2010], Mendonça [2007], Turoff et al. [2004, 2009], and Weick [1993]). However, none of these mobile map-based approaches addresses the improvisation practices related to ad hoc tasks in a collaborative manner. Approaches either do not consider ad hoc tasks in mobile contexts [Wu et al. 2013], do not focus on geo-collaborative aspects [Ludwig et al. 2013] or do not consider being able to ad hoc integrate new actors outside one's own organization to situation assessment [Monares et al. 2011].

We therefore explored the practice and necessities of mobile collaboration with regard to improvisation work and ad hoc participation of units in emergencies. We suggested, implemented, and evaluated an interaction concept including a real-time map with the potential of synchronous and very flexible information sharing. In our empirical study (Section 4) on current work practices of emergency services with regard to collaboration in situation assessment and decision-making activities, we found that the spontaneity and volatility of the emerging information needs of units poses a significant challenge to involving them efficiently, as well as providing a common situation assessment. The current practices show that a number of results need to be addressed when developing technological support for mobile ad hoc response work:

—Informal communication practices (mainly through mobile phones) are required to be able to respond to the dynamic nature of emergency scenarios.
—When individual actors are needed suddenly, mobile phone calls enable and guarantee their rapid ad hoc involvement into situation assessment.

—Besides the limitations of verbal speech, mobile phone calls with point-to-point communication lack the living-in-a-situation support and are therefore not able to facilitate situation awareness.

Based on these conditions and related to the observed work practices, we designed a mobile geo-collaboration application (Section 5). With this application as our basis, we implemented the innovative collaboration mode, which focuses on an ad hoc and collaborative situation assessment across many expert units with the requisite spontaneity. In addition to mobile phone calls, the decision to design a lightweight mobile application gives the units a technical option to involve additional forces into situation assessment and decision making. In addition to mobile phone calls, it provides a technical opportunity to involve organized volunteer forces, which are essential in German emergency management, but who are not as well equipped as the professionals. Such an option for involving participants who are needed on an ad hoc basis has potentially positive effects in three dimensions, as indicated by our evaluation (Section 6):

(1) *Spatial*: Multilateral visual support for on-site units and the control center. In collaboration mode, it is possible to enhance the existent improvisational verbal communication on mobile phones with the visualization and synchronous view of a situation, so that all needed units are able to *talk about the same situation.*
(2) *Organizational*: Cooperation with external (interorganizational) and volunteer units. In collaboration mode, it is possible to extend the improvisational communication and situation assessment practices in such a way that the inexpensive and often already existing private technical devices can be used to integrate additional organizations, particularly volunteer forces, into emergency management with the aim of *all talking together* about the same situation.
(3) *Temporal*: Time-independent available cooperation beyond office hours. In collaboration mode, it is possible to contact everyone not only outside of one's working environment, that is, a fixed desktop PC or situation map inside a control room, but also beyond typical office hours. Because an emergency does not occur on a time schedule, emergency services also have to comply with this time independence. With an application like MoCo on all actors' devices, it is possible for *everyone to talk together about the same situation whenever it is required.*

Aside from these positive effects, there is a major issue when developing concepts and tools that support informal practices and improvisation work in general. On the one hand, such solutions can support existing work practices that necessarily deviate from previously defined structures to enable a flexible response to any emergency. On the other hand, those developments undermine acknowledged, formal hierarchy structures, command chains, and processes as stated by legal regulations and professional conventions. Organizations have to accept these informal work practices and need to find compromises between predefined and actually executed procedures to create opportunities for technical support. If this does not happen, improvisation will be limited to verbal speech on mobile phone calls. Using private smartphones according to a bring-your-own-device policy may not be as reliable as specialized devices and will raise legal, organizational, and practical questions. However, to ad hoc integrate actors into situation assessment, the available devices have to be considered or rich collaboration cannot be established. McMaster and Baber [2012] point out the need to be able to share details of scenarios with experienced colleagues, who can summarize the situation in a few words. In any event, our study showed that these conversations might be enhanced by visual representations of the situation as provided by MoCo. In some cases, these representations cover all information needs of the respective units; in other cases, additional established verbal reporting structures [Schmidt and Bannon

1992] are necessary. By not just sharing all information, but with the opportunity to set private and public areas, reducing information overload [Hiltz and Turoff 1985] is also possible. Regardless, our point was that accurate and reliable information is necessary, not that it is sufficient. We do not see our application as interfering with, or problematizing, the skillful work practices of experienced members.

Emergency management and response work are not the only application field for which approaches for supporting the ad hoc participation in mobile collaboration are of value. Emergent or spontaneous collaboration will become much more important for organizations, businesses, and individuals in an increasingly networked world [Grudin 2010]. Working in emergent structures can be challenging due to unpredictability, incalculability, and therefore uncertainty. To deal with these circumstances, flexible applications supporting the needs of improvisational work by heterogeneous teams are required. These heterogeneous teams are not necessarily in the same location, same organization, or in the office when needed. Such flexibility is not always required and desired; however, the responsible actors in critical and volatile situations, such as emergency services, special operations, or responsible managers in business, may benefit from it. Our work illustrated three dimensions (spatial, organizational, and temporal) that might be covered by tools for ad hoc participation, and which potentially have ramifications that go beyond those planned [Orlikowski, 1997]. Basically, collaboration infrastructures are challenged to support collaborators, who are each embedded in a specific socio-spatial-temporal and organizational context in their effort to overcome the distance between them and to create a common ground for collaboration [Schmidt and Bannon 1992]. However, it seems likely that these dimensions are not the only ones that enact collaboration and have to be addressed in order to support the resilience of collaboration [Reuter 2014].

In the future, we intend to look into additional ways of improving *collaborative resilience* [Goldstein 2011], which "examines a variety of ways to build resilience to violence, hazards, and resource decline [. . .] such as the collective mobilization of change." We aim to find ways of identifying how citizens and spontaneous volunteers can be integrated into situation assessment as possible participants [Reuter et al. 2013; Starbird and Palen 2013; Vieweg et al. 2010]. Particularly in large-scale emergencies, the necessary actions can exceed the available manpower of professional and organized volunteer forces and offer potential for citizen involvement in response work [Reuter et al., 2012]. Such involvement also requires a great degree of coordination; our application has potential for wider-scale information sharing that can facilitate the process.

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REFERENCES

A. Adrot and D. Robey. 2008. Information technology, improvisation and crisis response: Review of literature and proposal for theory. In *Proceedings of Americas Conference on Information Systems (AMCIS'08)*.

F. Bergstrand and J. Landgren. 2011. Visual reporting in time-critical work: exploring video use in emergency response. In *Proceedings of the International Conference on Human Computer Interaction with Mobile Devices and Services (MobileHCI'11)*. 415–424.

O. W. Bertelsen and S. Bødker. 2001. Cooperation in massively distributed information spaces. In W. Prinz, M. Jarke, Y. Rogers, K. Schmidt, and V. Wulf (Eds.), *Proceedings of the European Conference on Computer Supported Cooperative Work (ECSCW'01)*. Kluwer Academic Publishers, 1–17.

M. Büscher and P. H. Mogensen. 2007. Designing for material practices of coordinating emergency teamwork. In B. Van De Walle, P. Burghardt, and C. Nieuwenhuis (Eds.), *Proceedings of the Information Systems*

for Crisis Response and Management (ISCRAM'07). Retrieved September 12, 2014 from http://www.ist-palcom.org/publications/files/ISCRAM_Buscher_Mogensen_final.pdf.

G. Cai. 2005. Extending distributed GIS to support geo-collaborative crisis management. *Geographic Information Science* 11, 1, 4–14.

T. Catarci, M. De Leoni, A. Marrella, M. Mecella, M. Bortenschlager, and R. Steinmann. 2010. The WORKPAD project experience: Improving the disaster response through process management and geo collaboration. In *Proceedings of the Information Systems for Crisis Response and Management (ISCRAM'10)*.

R. Chen, R. Sharman, H. R. Rao, and S. J. Upadhyaya. 2008. Coordination in emergency response management. *Communications of the ACM* 51, 5, 66–73.

G. Convertino, H. M. Mentis, A. Slavkovic, M. B. Rosson, and J. M. Carroll. 2011. Supporting common ground and awareness in emergency management planning. *ACM Transactions on Computer-Human Interaction (TOCHI)* 18, 4, 1–34.

M. R. Endsley. 1995. Toward a theory of situation awareness in dynamic systems. *Human Factors* 37, 1, 32–64.

B. E. Goldstein. 2011. *Collaborative Resilience—Moving Through Crisis to Opportunity.* MIT Press, Cambridge, MA, 376.

J. Grudin. 2010. CSCW: Time passed, tempest, and time past. *Interactions* 17, 4, 38–40.

J. Heard, S. Thakur, J. Losego, and K. Galluppi. 2014. Big board: Teleconferencing over maps for shared situational awareness. *Computer Supported Cooperative Work: The Journal of Collaborative Computing (JCSCW)* 23, 1, 51–74. doi:10.1007/s10606-013-9191-9

A. Hevner and S. Chatterjee. 2010. *Design Research in Information Systems: Theory and Practice.* Springer.

A. Hevner, S. T. March, J. Park, and S. Ram. 2004. Design science in information systems research. *MIS Quarterly* 28, 1, 75–105.

S. R. Hiltz, P. Diaz, and G. Mark. 2011. Introduction: Social media and collaborative systems for crisis management. *ACM Transactions on Computer-Human Interaction (TOCHI)* 18, 4, 1–6.

S. R. Hiltz and M. Turoff. 1985. Structuring computer-mediated communication systems to avoid information overload. *Communications of the ACM*, 28, 7, 680–689.

S. R. Hiltz, B. van de Walle, and M. Turoff. 2011. The domain of emergency management information. In B. Van De M. Walle Turoff, and S. R. Hiltz (Eds.), *Information Systems for Emergency Management*. M. E. Sharpe, New York, NY, 3–20.

R. Johansen. 1988. *GroupWare: Computer Support for Business Teams*. The Free Press, New York, NY.

R. E. Kraut, D. Gergle, and S. Fussell. 2002. The use of visual information in shared visual spaces: Informing the development of virtual co-presence. In *Proceedings of the Conference on Computer Supported Cooperative Work (CSCW'02)*. ACM, New York, NY.

G. H. Kwon, T. L. Smith-Jackson, and C. W. Bostian. 2011. Socio-cognitive aspects of interoperability: Understanding communication task environments among different organizations. *ACM Transactions on Computer-Human Interaction (TOCHI)* 18, 4, 1–21. doi:10.1145/2063231.2063234

J. Landgren. 2006. Making action visible in time-critical work. In *Proceedings of the Conference on Human Factors in Computing Systems (CHI'06).* ACM, New York, NY, 201–210.

G. H. Lewes. 1875. *Problems of Life and Mind*. Osgood, London, UK.

K. Lewin. 1958. *Group Decision and Social Change*. Holt, Rinehart and Winston, New York, NY.

B. Ley, T. Ludwig, V. Pipek, D. Randall, C. Reuter, and T. Wiedenhoefer. 2014. Information and expertise sharing in inter-organizational crisis management. *Computer Supported Cooperative Work: The Journal of Collaborative Computing (JCSCW)* 23, 4–6, 347–387.

B. Ley, V. Pipek, C. Reuter, and T. Wiedenhoefer. 2012. Supporting improvisation work in inter-organizational crisis management. In *Proceedings of the Conference on Human Factors in Computing Systems (CHI'12).* ACM, New York, NY, 1529–1538.

B. Ley, V. Pipek, T. Siebigteroth, and T. Wiedenhoefer. 2013. Retrieving and exchanging of information in inter-organizational crisis management. In *Proceedings of the Information Systems for Crisis Response and Management (ISCRAM'13)*. Baden-Baden, Germany, 812–822.

S. Lindström and M. Pettersson. 2010. Supporting ad-hoc re-planning and shareability at large-scale events. In *Proceedings of International Conference on Supporting Group Work (GROUP'10).* ACM, New York, NY, 245–252.

S. B. Liu and L. Palen. 2010. The new cartographers: Crisis map mashups and the emergence of neogeographic practice. *Cartography and Geographic Information Science* 37, 1, 69–90.

T. Ludwig, C. Reuter, and V. Pipek. 2013. What you see is what I need: Mobile reporting practices in emergencies. In O. W. Bertelsen, L. Ciolfi, A. Grasso, and G. A. Papadopoulos (Eds.), *Proceedings*

of the European Conference on Computer Supported Cooperative Work (ECSCW'13). Springer, 181–206.

R. McMaster and C. Baber. 2012. Multi-agency operations: Cooperation during flooding. *Applied Ergonomics* 43, 1, 38–47. doi:10.1016/j.apergo.2011.03.006

D. Mendonça. 2007. Decision support for improvisation in response to extreme events: Learning from the response to the 2001 World Trade Center attack. *Decision Support Systems* 43, 3, 952–967. doi:10.1016/j.dss.2005.05.025

A. Monares, S. F. Ochoa, J. A. Pino, V. Herskovic, J. Rodriguez-Covili, and A. Neyem. 2011. Mobile computing in urban emergency situations: Improving the support to firefighters in the field. *Expert Systems with Applications*, 38, 2, 1255–1267. doi:10.1016/j.eswa.2010.05.018

E. G. Nilsson and K. Stølen. 2010. Ad hoc networks and mobile devices in emergency response—a perfect match? *Ad Hoc Networks—Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunication Engineering*, 49, 17–33.

W. J. Orlikowski. 1997. Evolving with notes: Organizational change around groupware technology. In C. U. Ciborra (Ed.), *Groupware and Teamwork.* John Wiley and Sons, New York, NY, 23–59.

L. Palen and S. B. Liu. 2007. Citizen communications in crisis: Anticipating a future of ICT-supported public participation. In *Proceedings of the Conference on Human Factors in Computing Systems (CHI'07)*. ACM, New York NY, 727–736.

C. Y. Peng, W. S. Kao, Y. Z. Liang, and W. K. Chiou. 2007. The practices of scenario observation approach in defining medical tablet PC applications. In *Human-Computer Interaction.* Lecture Notes in Computer Science (Vol. 4553). Springer, 518–524.

E. L. Quarantelli. 1988. Disaster crisis management: A summary of research findings. *Journal of Management Studies* 25, 4, 373–385. Retrieved September 12, 2014 from http://udspace.udel.edu/bitstream/handle/19716/487/PP113.pdf.

E. L. Rakea and O. Njå. 2009. Perceptions and performances of experienced incident commanders. *Journal of Risk Research* 12, 5, 665–685.

C. Reuter. 2014. *Emergent Collaboration Infrastructures: Technology Design for Inter-Organizational Crisis Management*. Ph.D. thesis. University of Siegen, Siegen.

C. Reuter, O. Heger, and V. Pipek. 2013. Combining real and virtual volunteers through social media. In T. Comes, F. Fiedrich, S. Fortier, J. Geldermann, and T. Müller (Eds.), *Proceedings of the Information Systems for Crisis Response and Management (ISCRAM'13)*. Baden-Baden, Germany, 780–790.

C. Reuter, A. Marx, and V. Pipek. 2012. Crisis management 2.0: Towards a systematization of social software use in crisis situations. *International Journal of Information Systems for Crisis Response and Management (IJISCRAM)* 4, 1, 1–16.

C. Reuter and M. Ritzkatis. 2013. Unterstützung mobiler Geo-Kollaboration zur Lageeinschätzung von Feuerwehr und Polizei. In R. Alt and B. Franczyk (Eds.), *Proceedings of the International Conference on Wirtschaftsinformatik.* 1877–1891. Retrieved September 12, 2014 from http://aisel.aisnet.org/wi2013/117.

W. Schafer, C. H. Ganoe, and J. M. Carroll. 2007. Supporting community emergency management planning through a geocollaboration software architecture. *Computer Supported Cooperative Work: The Journal of Collaborative Computing (JCSCW)* 16, 4–5, 501–537. doi:10.1007/s10606-007-9050-7

C. Schmidt. 2004. The analysis of semi-structured interviews. In U. Flick, E. V. Kardorff, and I. Steinke (Eds.), *A Companion to Qualitative Research*. Sage, London, UK, 253–258.

K. Schmidt and L. Bannon. 1992. Taking CSCW seriously: Supporting articulation work. *Cooperative Work and Coordinative Practices*, 1, 1, 1–33. Retrieved September 12, 2014 from http://www.springerlink.com/index/P27V3670L1V03442.pdf.

J. Schöning, M. Rohs, A. Krüger, and C. Stasch. 2009. Improving the communication of spatial information in crisis response by combining paper maps and mobile devices. In J. Löffler and M. Klann (Eds.), *Mobile Response* (Vol. 5424). 57–65.

B. Semaan and G. Mark. 2011. Technology-mediated social arrangements to resolve breakdowns in infrastructure during ongoing disruption. *ACM Transactions on Computer-Human Interaction (TOCHI)* 18, 4, 1–21. doi:10.1145/2063231.2063235

K. Starbird and L. Palen. 2013. Working and sustaining the virtual "Disaster Desk." In *Proceedings of the Conference on Computer Supported Cooperative Work (CSCW'13).* ACM, New York, NY, 491–502. doi:10.1145/2441776.2441832

A. L. Strauss. 1987. *Qualitative Analysis for Social Scientists*. Cambridge Press, Cambridge, MA.

E. Tamaru, K. Hasuike, and M. Tozaki. 2005. Cellular phone as a collaboration tool that empowers and changes the way of mobile work: Focus on three fields of work. In *Proceedings of the European Conference on Computer-Supported Cooperative Work (ECSCW'05)*. Springer-Verlag, 247–266.

M. Turoff, M. Chumer, B. van de Walle, and X. Yao. 2004. The design of a dynamic emergency response management information system (DERMIS). *The Journal of Information Technology Theory and Application (JITTA)* 5, 4, 1–35. Retrieved September 12, 2014 from http://aisel.aisnet.org/jitta/vol5/iss4/3.

M. Turoff, S. R. Hiltz, C. White, L. Plotnick, A. Hendela, and X. Yao. 2009. The past as the future for emergency planning and response. *International Journal of Information Systems for Crisis Response and Management (IJISCRAM)* 1, 1, 12–28.

S. Vieweg, A. L. Hughes, K. Starbird, and L. Palen. 2010. Microblogging during two natural hazards events: What Twitter may contribute to situational awareness. In *Proceedings of the Conference on Human Factors in Computing Systems (CHI'10)*. ACM, New York, NY, 1079–1088.

K. E. Weick. 1993. The collapse of sensemaking in organizations: The Mann Gulch disaster. *Administrative Science Quarterly* 38, 4, 628–652. Retrieved September 12, 2014 from http://www.jstor.org/stable/10.2307/2393339.

D. Wenger, E. L. Quarantelli, and R. R. Dynes. 1989. *Disaster Analysis: Police and Fire Departments*. University of Delaware, Disaster Research Center. Retrieved September 12, 2014 from http://udspace.udel.edu/handle/19716/1141.

A. Wu, G. Convertino, C. H. Ganoe, J. M. Carroll, and X. L. Zhang. 2013. Supporting collaborative sense-making in emergency management through geo-visualization. *International Journal of Human-Computer Studies (IJHCS)* 71, 1, 4–23. doi:10.1016/j.ijhcs.2012.07.007

V. Wulf, M. Rohde, V. Pipek, and G. Stevens. 2011. Engaging with practices: Design case studies as a research framework in CSCW. In *Proceedings of the Conference on Computer Supported Cooperative Work (CSCW'11)*. ACM, New York, NY, 505–512.

S. Zlatanova and A. G. Fabbri. 2009. Geo-ICT for risk and disaster management. In H. J. Scholten, R. Velde, and N. van Manen (Eds.), *Geospatial Technology and the Role of Location in Science*. Springer, 1–22. Retrieved September 12, 2014 from http://www.springer.com/earth+sciences+and+geography/geographical+information+systems/book/978-90-481-2619-4.

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