Information and Communication Systems for Mobile Emergency Response

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Abstract. This discussion paper attempts to propose emergency response and disaster management as worthwhile areas of applied research for the information system community. The typical requirements, entities and activities involved in specifically mobile emergency response operations are summarized. Recent research contributions in this area are exemplarily reviewed in order to give a deeper insight into the role and use of mobile information and communication systems. Finally, the major challenges and research needs regarding information systems are summarized, with a view to draw the attention of information systems researchers to this interesting and important field.

Keywords: Emergency response, disaster management, information systems, mobile information and communication technology

1 Introduction

Recently, there has been an increased research interest in deploying information technology (IT) in the area of disaster management and emergency response. Until a few years ago, the use of IT in this field was quite limited, but its potential for increasing the effectiveness of disaster response and recovery was well acknowledged, and technology and design proposals for integrated communication and information systems for disaster management came up [1].

In 2003, an international community was established with the goal of sharing knowledge and views regarding design and use of information systems in this field of research. This community was named ISCRAM – International Community on Information Systems for Crisis Response And Management [2]. Additionally, several research projects as well as conference and workshop series have been launched to address different aspects in this area.

Today, the IT branch considered most promising for the emergency response (ER) area is clearly *mobile* IT, simply because “an important part of this work is done in the field”, yet “with little or no infrastructure to rely on” (cited from the preface of [3], the initial workshop of a dedicated series for mobile ER). Since “a primary challenge in responding to […] disasters is communication” [4], the authors of this paper, researchers in multimedia communication, decided to extend their work to this worthwhile area. After all, multimedia data such as images and video clips of a disaster site, or GIS information or presentations augmenting the reality of ER personnel, for instance, are gaining importance for ER operations. However, the underlying on-site communication infrastructure for these types of data is typically wireless, mobile, changing dynamically, in an ad hoc manner. These properties make research on multimedia communication in these environments an interesting endeavor.

Yet, in this discussion paper we intend to point out the role of, and the challenges for, information systems (IS) in mobile ER, in order to make the IS research community aware of this important application area and the research questions involved. Even as far as IS are concerned, the adoption of technology seems to be slow: “the use of IT is oftentimes still limited to the stationary headquarter dispatch system” [5], where “dispatch” denotes the activity of planning and sending resources (ER personnel, vehicles and material) to a disaster site and monitoring the response operation.

To show how information and communication systems may contribute to efficient and effective ER, we first review the typical entities, organization and operation of emergency services in Section 2. In Section 3, we exemplarily describe specific aspects and recent research contributions regarding mobile IT for ER (mainly from [3]), structured along the typical information flow in response and rescue operations. Section 4 attempts to work out the major research questions in the IS field that need to be addressed, and Section 5 provides concluding remarks.

2 Mobile Emergency Response Operations

A coarse classification for different types of disasters is given in [6] as follows:

- *Man-made* disasters, such as terrorist attacks, plane crashes, fire blasts
- *Natural* disasters, such as earthquakes, flood waves, tsunamis, avalanches
- *Epidemic or pandemic* disasters, such as widespread viruses and diseases.

Since in this approach some emergency situations may be classified in two or even all classes, this differentiation is not enough to derive special characteristics. A more specific distinction concerns the step-wise description of the process of ER [6]:

- *Detection* of an incident by searching the environment
- *Assessment* and classification of an observed incident
- *Alerting* responsible entities with the aim to respond
- *Mitigation* and planning of response activities
- Actual *response* and engagement of necessary resources
- *Recovery* and rehabilitation.

Depending on the particular characteristics and requirements of a disaster type or certain step in the process chain, different strategies and procedures regarding mobile emergency response have to be developed. In an attempt, though, to work out the typical entities and organization of disaster and emergency response operations and of corresponding communication, information and management systems, Figure 1 depicts the most common three-tier arrangement [1].

On the *strategic* level, the headquarters of public emergency agencies like police, fire departments, medical services, civil defense and other organizations, are alerted of a disaster situation, plan, allocate and dispatch the resources to respond to the incident, monitor their operations, provide information (e.g., maps) and instructions to the emergency site and re-allocate resources, if needed. Ideally, the decisions and activities among the different public emergency services are coordinated, also by means of and in terms of the involved IS. In large-scale disasters, consultation and coordination with government authorities is required as well.

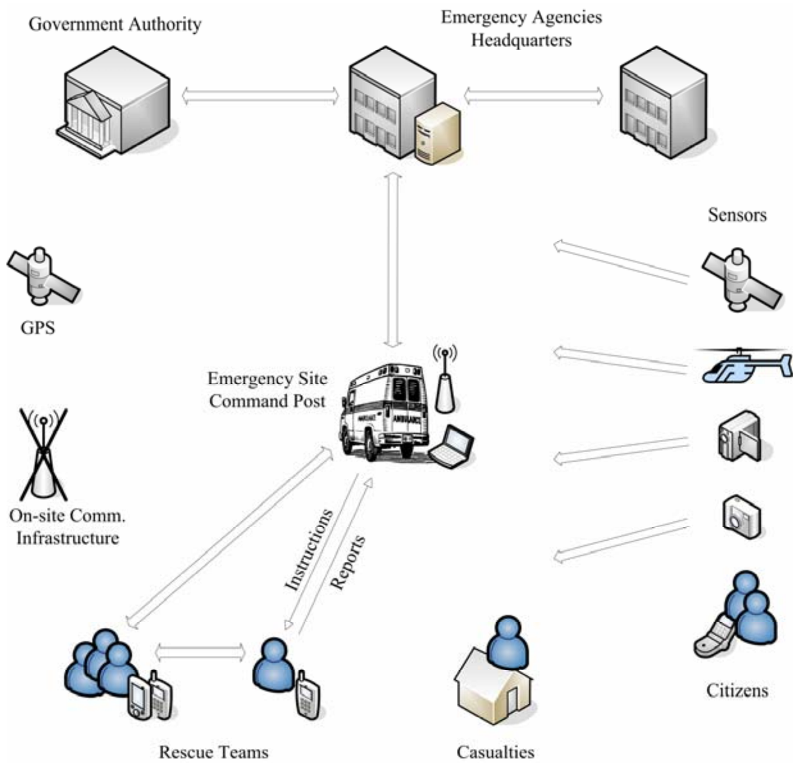

Fig. 1 Three-tier organization of entities and operations in an emergency response scenario

On the *tactical* level, officers in the so-called (mobile) command post on the emergency site are responsible for on-site command and control of, and communication with, the rescue teams and/or individuals. Here, the on-site, dynamically changing operational picture (situational awareness), derived from the reports and data delivered by the responders and, increasingly, sensors, will lead to informed decisions and instructions on targeted actions to be performed by the response personnel. In other words, the task to be coped with on this level is basically “coordination of resources in space and time”, yet in a hostile and risky space and mostly under significant time pressure [7]. The timeliness, precision and completeness of the information, decisions and instructions are crucial for the effectiveness of the operations and the safety of the response teams. The problem on this level is that an intact communication infrastructure cannot be assumed, yet reliable communication has highest priority. For voice communication, specific radio networks like TETRA are usually being employed in order to avoid “chaos in the air” resulting from traditional broadcast-type radio channels [1]. However, other data communication may have to take place over ad hoc, unreliable networks. A further issue is that some information needed for the response operation may not be available on site, but must be requested from the strategic level, e.g., a specific map, picture or stock list of hazardous goods.

On the *operational* level, the primary concern of the teams of responders is to provide immediate relief, medical care or other assistance to survivors, to fight the disastrous conditions (e.g., fire) or to find victims. Depending on the current situational view and their experience, the responders may adapt the decisions and instructions of the commanding officer or even the team leader in order to deliver the most effective help or not to risk their own lives. For their operation, it is of minor importance and mostly distractive to acquire data or to send reports about their situation to the commanders, thus data are increasingly being read from sensors and communicated to the tactical level automatically, e.g., vital parameters and amount of pressurized air of firefighters. The responders are now data sources, but clearly also data sinks, receiving, e.g., instruction messages, maps or data on missing persons [1]. Furthermore, they need to communicate and exchange data among themselves.

As already indicated above and illustrated in Figure 1, there are other data sources that may provide data (push mode) or may be requested data from (pull mode). On the one hand, civilians may offer or provide assistance and, e.g., be able to contribute pictures or video material to the response operations. On the other hand, several external sensor systems or sensor networks may be queried to deliver important data, e.g., GPS coordinates (most frequently used), video surveillance footage, aerial or satellite imagery, weather parameters, or measurements on toxic gases. This data may be requested by or supplied to any level in the hierarchy of ER entities.

Table 1 summarizes the major responsibilities, activities and characteristics pertaining to the entities involved in disaster response operations.

Entities *Characteristics*	*Govmt. authorities Emergency agency*	*Emergency site command officer*	*Individual or team of responders*
Level of decisions and activities	Strategic	Tactical	Operational
Major responsibilities	Planning, resource allocation, dispatch, decisions, coordination, predictions	Dynamic on-site coordination of emergency forces	Immediate aid, relief, medical care, direct assistance
Data intensity of activities	High: exclusively based on data	Medium: dependent on precise and timely data	Low: minimum use of data desired
Data abstraction, aggregation level	High: mostly in aggregated form	Medium: aggregated situational view	Low: specific situational data
Spatial range of activities	Global	Emergency site	Local
Temporal scale of activities	Long	Medium	Short
Mobility	None or low	Low or medium	High

Table 1 Major activities and characteristics of entities involved in emergency response

3 Information Flow in Mobile Emergency Response Situations

The flow of information between the involved entities as introduced above and, thus, the role and contributions of information systems can be considered as the most important factor regarding a successful mobile response to a disaster or emergency situation. In this context, different questions have to be asked:

- What information is necessary?
- How can the information be communicated (re. interfaces, devices, and networks)?
- Who is involved in the information flow?
- Where is the information required?
- What is the information used for and how long is it needed (persistency issues)?

The following sections attempt to summarize different recent approaches regarding the above identified questions. This is intended to give a more detailed picture of the requirements and procedures of mobile emergency response operations.

3.1 What Information Is Necessary?

It is crucial that certain information about the incident and conditions of involved people is communicated to the response teams. Several report categories including different information are required to handle a mobile response situation [8]:

- Mission related data such as administrative or insurance data
- Information about the incident itself (time and date of call, location of the incident, situational reports, etc.), which may differ widely among different ER agencies
- Clinical information (observation of vital signals, pupils, skin, etc.)
- Medical treatment/measurements such as defibrillation and medication
- Results and transfer data (assessment of injuries on handover).

Besides this basically patient-based and incident-based information, other contextual information such as the current location of a user, current time or the time of past or present events, user activities, user preferences and profiles of users should be considered. Information collected from disaster monitoring systems may also be needed to respond accurately.

Additionally, information regarding devices and networks, i.e., the information and communication system itself, is required. In order to achieve an improvement of the communication infrastructure of a mobile ER information system, information from two different domains is used: semantic information about the communication system itself (e.g., the purpose of deployment of the system) and information that can be extracted directly from the infrastructure (by evaluating network structure and activities, e.g., performance parameters). These two domains are not necessarily unrelated, as knowledge about semantics can be extracted from particular network activity.

3.2 How Can the Information Be Communicated?

In disaster response scenarios, the necessary information has to be communicated as fast and accurately as possible to the responsible entities. Failures or shortcomings regarding communication can sometimes make the difference between life and death [9]. Therefore, the used interfaces and devices as well as the underlying communication networks have to suit certain demands.

Visualization and Interfaces

An important aspect in a mobile response scenario is the evolution from paper-based emergency report forms to electronic solutions to document medical necessities and procedures at emergency scenes [8]. One simple but important advantage of electronic solutions is that immediate electronic transmission of patient data and diagnoses is provided, allowing an early preparation of involved entities, e.g., headquarters or hospitals. The paper-based information used to arrive comparatively late, e.g., together with the patient at the targeted hospital where both were handed over to the emergency department simultaneously. Other objectives that can be achieved by electronic solutions include simple, fast, and mobile data acquisition and collection, as well as automatic localization possibilities (via GPS) [10].

Recently, there have been nation-wide efforts of countries for logging and recording data in medical emergency situations. However, a cross-national (e.g., European) documentation to support an emergency situation affecting several countries – such as a natural disaster – is not yet available. In order to increase the collaboration and common quality level of medical procedures in emergency situations, the standardization and cooperation of medical emergency systems is desirable [8]. Research efforts in this direction are for example the *European Emergency Data* project (EED) [11] or the *Hesculaep* project [12], both supported by the European Union.

In order to provide documentation of the needed information in a clear and easy way for all involved entities, text and graphical elements are used to illustrate the information. Examples of the graphical representation are icons indicating a certain characteristic such as a fracture or burns, or a drawing of a human body illustrating different kinds of injuries at different body locations with different severity by highlighting the anatomical portions in different colors [8]. An automatic color coding of the fields based on the entered values can be helpful to give a quick idea of how close or far the clinical values are from normality. It has to be guaranteed that the illustrations are both, big enough to be readable and selectable on a touch-screen by a finger or a stylus, and anatomically detailed enough to provide for a detailed, meaningful analysis of the injuries [8]. Additionally, this approach can be used to provide quick feedback by highlighting possible input errors [9]. Regarding text input, an interesting way to support the ER teams is handwriting recognition and generally recognition of pen-input [13], or to provide an on-screen virtual keyboard with automatic word completion [9]. In general, a system that is too complex will most likely not be accepted by the mobile response team [8].

Multi-modal interfaces proved to be especially important for disaster response scenarios. The goal of these approaches is to provide a connection to an interactive system with different kinds of hands-free input possibilities, such as speech input or pointing to objects. E.g., project *AMIRA* [14] addresses several issues regarding multi-modal intelligence, with a focus on speech interaction. However, the utilization of only speech recognition is sometimes limited or not appropriate, due to environmental noise in ambulance trucks or helicopters [9].

Mobile Response Devices

A straightforward approach is to apply Tablet PCs or PDAs as communication devices in mobile ER situations. In [10], an overview of special requirements regarding the hardware is presented. The size of the display has to be small to be wearable, but on the other hand, the information needed must be visible and interaction with fingertips or a stylus on a touch screen has to be provided. Most display sizes of PDAs are comparably small, whereas the bigger sizes of Tablet PCs might result in unhandiness in a response situation. Another important aspect regards the weight of the handhelds, which should be minimal in emergency situations in order not to interfere with the rescue efforts. Energy-aware devices and a long battery lifetime are necessary to support the working hours of the emergency personnel. Features such as charging the device inside a vehicle should be considered to improve the availability of the devices. In order to operate in a disaster or emergency situation, special coatings and sealants for the hardware are needed. The protection is necessary if the devices are exposed to extreme temperatures, humidity, water sprays, dust and vibration.

In order to evolve from simple handheld devices to wearable “hands-free” devices, a first approach is the integration of handhelds into ER vehicles or into the clothing. In [8], the integration of a suitable PDA into a special environment suit for the medical personnel is presented. The display content of the PDA is visualized by a head-up display. Additionally, speech recognition is included to navigate and control the program in order to provide a hands-free approach that could be an advantage for physicians and other responsible persons.

A desirable approach is to include smart sensor systems, i.e., micro- and nanotechnology-based wearable equipment that can be directly integrated into garments and textiles. These systems are furthermore able to record heart and respiratory rate, temperatures, as well as the absolute position via GPS. In [15], the design of garments and textile sensors is discussed in detail. Also IST projects are interested in the applicability of computer systems that are integrated in clothes. E.g., the objective of *wearIT@work* is to support users in unobtrusive ways by wearing computer systems including sensors as a computer-belt [16].

Networking Issues

In emergency situations, an efficient communication system is crucial to be able to exchange the information collected in different areas. Disasters such as earthquakes or hurricanes can cause an existing communication infrastructure (e.g., telecommunication) to get damaged [17]. Therefore, a number of research activities deal with the establishment and operation of mobile ad-hoc networks, spontaneous networks composed of single nodes communicating with each other, without having a fixed infrastructure as in common IEEE 802.11 wireless networks.

3.3 Who Is Involved in the Information Flow?

The question of which entities are involved in an emergency response scenario can – at a first glance – be answered intuitively, as done in Section 2: the headquarters of the response activity, the on-site command and control post, the mobile rescue teams, as well as probably hospitals or other reception camps. However, if we consider that the information is communicated over a physical network, the flow of information can affect several other entities as well. Assuming an ad-hoc network infrastructure as discussed in Section 2, all nearby communication nodes can work together to allow for a stable communication. Thus, patients and passers-by can just as well contribute to the information flow as a helicopter surveying the surroundings, a wireless access point in a nearby building, or a robot participating in the response mission.

3.4 Where Is the Information Required?

Before this question can be answered, a more important aspect has to be addressed. It is crucial to identify where "where" is, i.e., spatial considerations regarding the participants in an information flow have to be made. In the emergency domain, much relevant information is inherently attached to places – and therefore "spatial" [18].

With the currently available GPS technology, it is possible to locate the (almost) exact position of a person. Location-based services exploit this technology to offer the user services that are of special interest for users in this area, without the need to enter a ZIP code or any other form of spatial information.

An enhancement of location-based services is mobile spatial interaction. This approach allows combining digital information with the user's direct surroundings [18]. Mobile spatial interaction has been discussed for several years, in [19] a next generation GIS is presented, featuring Smart Compasses, Smart Horizons, Smart Glasses, and Geo-Wands. These appliances combine a hand-held computer with a GPS receiver, a cellular phone, and a digital camera and enable the user to integrate spatial analysis into daily life activities. For ER situations, these spatially aware mobile phones could provide meaningful interaction with real-world objects, e.g., by attaching meaningful information (such as a label) to 3D objects or segments of the user's surroundings. Continuous interplay of virtual and spatial information by overlaying the user's field of view could be realized by devices like Smart Horizons or Smart Glasses. Another advantage of mobile spatial interaction over location-based systems is that a more accurate selection of, e.g., parts of a building, or a street is possible. This more fine-grained approach allows adding tags, e.g., only to a specific part of the roof that is of interest for the mission. Project *Point-to-Discover* by the Telecommunications Research Center Vienna tries to develop technical foundations for mobile spatial interaction [18].

The *SHARE* project [20] uses intelligent visualizations to support the operation management by giving "everybody the right information at the right time in the right way" [21]. The data regarding spatial information (such as streets, buildings, and infrastructure) is stored in spatial database management system (PostGIS, Oracle10g) that provides secure and fast transaction mechanisms. The information can be accessed through a map server (Geo Server) and interoperable Map Web Services to support different output devices (PCs, PDAs, laptops). Domain knowledge is used to represent the data and processes in a semantic structure, in order to allow queries for different purposes. E.g., a request regarding available water resources in a special area results in a list including the existing hydrants in a 500 m circle around the user's position (using a spatial filter) [22].

If the location information is available, it is important to decide where which information is needed, as well as when it is needed. The management of resources and data in search and rescue operations, most times supervised by the commander at the headquarters, is crucial. For example, spatial information can help by coordinating search activities or illustrating the spread debris at a crash site. However, all types of contextual information as discussed above can support to organize and manage the rescue mission and related processes.

3.5 What Is the Information Used For and How Long Is It Needed?

The first part of the question pertains to the major ER entities, responsibilities and activities as pointed out in Section 2, specifically in Table 1, and is thus not further detailed here.

The information obtained regarding the environment of an ER situation has different importance at different times. Some data is needed only for a very short moment, such as the current pulse rate of a patient or a currently available communication path in ad-hoc networks. Information about the current location of a user is only valid and interesting as long as the user remains at this position. Other data, however, can be important for the whole response action. Examples for such information are the location of the incident or the number of affected people and rescue teams. And then there is information that might be of concern for a long time, beyond one rescue mission. For use in post-disaster analyses as well as for simulation and training purposes, it is important to have a detailed log of the situational analyses, communication processes and information exchange during the response operations; future missions and the skills of the response teams (at all levels) can heavily benefit from such data. Other persistent data can be related to the diagnosis and medical treatment of casualties.

The comprehensive knowledge base that evolves if all possibly related information is merged, analyzed, and evaluated, can support decisions. An accurate representation of the knowledge, e.g., in ontologies, can help to make decisions by using reasoning systems, and thus, save lives. The project *AMIRA* [14] combines various components to enable the creation of a diagnostic and decision support applications for the management of critical incidents such as emergencies or disasters. Example components in AMIRA are a knowledge engine and a case-based reasoning approach [14]. Systems for collecting and handling emergency medical care data can as well significantly improve the effectiveness of rescue operations. Relevant information are efficiently recorded and communicated between on-site teams and headquarters. Additionally, an on-site patient classification is possible, by using information from medical databases to decide a proper course of action in the field [9].

4 Research Needs

In this section, we attempt to summarize the major research needs for (mobile) emergency response, mainly pertaining to the deployment and further development of information systems. This summary is inspired by our study as partially laid out before, as well as by [1], [6], [7], [14], and [23] (cited and excerpted in [7]). Communication issues are not covered in the following since they are of minor importance to the IS community.

- *Interoperability of information systems* (and of other technologies and of working practices). Large-scale disaster response is a multi-agency, multi-entity, complex operation that requires close coordination among the agencies and responders. While information systems should support these coordination actions and provide a consistent “joint operational picture” [7], the current status is that the jurisdictions, terminologies, deployed systems, data models, views, etc. do not interoperate across agencies, let alone across nations. Semantic Web technologies in general seem to provide appropriate means to address these obstacles. Standardization efforts like the ones of the OASIS Emergency Management Technical Committee [24] are underway and have produced standards like the Common Alerting Protocol (CAP) and the Emergency Data Exchange Language (EDXL) [25], but need to be extended for coordination on the strategic and tactical levels to become more efficient and effective.
- *Knowledge representation/management and decision support.* The activities involved in disaster response on the strategic and tactical levels, i.e., in general, resource management and coordination, are based on informed decisions and resulting targeted actions. The decisions rely on current situational awareness, the emergency agencies’ rules, guidelines and procedures, and the expertise of the people involved, but should also make use of prior knowledge in the field, similar earlier cases and of experience of people not concerned with the mission at hand. Such rich, partially archival knowledge and its use calls for advanced techniques for knowledge representation and management as well as for systems that support the sense-making and decision-taking processes [26]. Again, techniques from Semantic Systems and Artificial Intelligence, like ontologies, case-based reasoning as described above and other conceptualizations as well as planning and reasoning techniques [27] have to be investigated and adopted here.
- *Flexible workflows and services.* Emergency response operations can be modeled as workflows, yet they must be extremely flexible since new events and information on the emergency situation can at any time significantly change the picture and modify the ER requirements and the processes taking place. The major issue is that the exchange of data and information can happen spontaneously and among any participating entities, thus comprehensive planning for workflow modifications in advance becomes impossible. A new IS architecture based on the Actor-Agent Communities (AAC) model was proposed here [6], where humans (actors) and software components (agents) form a complex network of autonomous information processing entities that collaborate. Other work [1] (as early as 2002) proposes a model of flexible and diverse information services where services configure themselves “dynamically and automatically” and “present the right data to the right actor at the right time with as little human intervention as possible” [1]. We are convinced that recent developments and achievements in the (Semantic) Web Services and Service Oriented Architectures research fields can bring most valuable contributions to IS for disaster response applications and need to be incorporated.
- *Rich data and information integration.* As indicated in Figure 1 and discussed in Section 2, disaster management involves a multitude of heterogeneous, distributed

and dynamically changing data sources and data sets, ranging from maps and other GIS data to recorded voice messages, images and videos, and to governmental databases. Even "outsiders" like civilians not directly involved in the incident and several sensor data sources may provide valuable data and information to the response operations. It is a specific challenge for IS to be open for accepting and integrating such rich data from diverse, probably unknown sources, to correlate (fuse) several data instances for a consistent situational picture, and to transfer the data and information to the right responsible entities. A prototype system was presented in [28]. In this context, security is of utmost concern since such openness can be abused for malicious attacks on the whole ER operation.

5 Conclusion

This discussion paper gave an overview of requirements, entities and activities involved in emergency response operations, mainly utilizing mobile information and communication technology (ICT). Selected recent research approaches and contributions were reviewed to give a more detailed picture of the problems involved in deploying ICT for disaster response activities. Subsequently, major research needs in the information systems area were worked out.

In conclusion, we are convinced that the major IS-related challenges of disaster response operations – namely, interoperability of information systems, knowledge representation and management, decision support, provisioning of flexible workflows and services, integration of rich data sets and information – can be successfully addressed using modern concepts and techniques from the research areas Service Oriented Architectures, Semantic Systems, Artificial Intelligence, Semantic Web, and Information Security. The IS community is invited to consider emergency response and disaster management as a challenging and worthwhile area for their research.

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