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An Interdisciplinary Approach to Designing a Mass Casualty Incident Management System

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***Abstract*—Efficient emergency management requires on the one hand collecting distributed pieces of information in order to get an aggregated situation overview, and on the other hand distributing and presenting the gathered information to all levels of decision making. IT-supported emergency management systems can support these tasks, but need to be carefully designed in order to reflect the actual needs. Robustness and user-friendliness are obvious key requirements for this area of application, but a thorough understanding of operational procedures is mandatory, too. This paper gives a brief description of the steps taken for the e-Triage research project, in which an IT-supported management system for mass casualty incidents (MCIs) is under development. A specific characteristic of the approach is that not only users as customers and engineers as vendors are involved, but also psychologists focussing on acceptance and ergonomics in terms of stress load caused by the developed solutions.**

I. Introduction

Appropriate communication systems are the key to successful coordination of rescue operations. Albeit the most important and most commonly used means to exchange information is voice, there are several application areas in which data exchange can support operation control. Management of mass casualty incidents (MCIs) with IT-supported triage and registration of affected persons is an example requiring both an appropriate communication architecture and suitable data management. Current state of the art is that MCI management is accomplished with paper-based systems, but an electronic approach promises faster situation overview and, thus, faster treatment of affected persons.

The design and implementation of such a system cannot be carried out unless a careful analysis of the requirements demanded by rescue professionals, who will be the users of the system, has been performed. Nevertheless, due to the nature of this kind of operations, where each rescue team has a defined protocol to be followed and where the high level of stress plays an important role, the introduction of new systems and procedures must be done in a sensible way, so that the system adapts itself to the current practices and not the other way round. Besides it may not increase the stress level experienced by the rescue personnel.

With this background in mind, the e-Triage project [1] proposes a rapidly-deployable patient management system to ease the registration and triage of victims, which is based on four main pillars: reliable and robust communication infrastructure, intuitive data gathering and data visualization, automatic replication and dissemination of collected data, and psychological acceptance research.

The objectives of the paper are to describe the process to design and implement the system focusing on the users' requirements, to identify the relevant features that the system must incorporate to achieve its functionality, and to describe the implementation process that reflects the analyzed requirements. The work is divided in several sections. Section II describes the process for gathering and analyzing the requirements from the users. Section III explains the implementation process according to the results described in Section II, and finally, conclusions from the whole process are derived in Section IV.

II. From User Requirements to Trials

The e-Triage project is based on close interaction with users, who have assisted the technical and scientific team during the design, implementation and testing phases in order to devise a product as close to their needs as possible. In the following we describe the approach used to gather user requirements and reflect them in the final solution, taking into account the different steps followed in the process and the inputs and outputs obtained at every stage.

A. Analysis of the Current Situation and User Requirements

The first step in order to design the system was to perform an analysis of courses of action to carry out MCI management. Since one of the main objectives of the project is to develop a system that interferes as little as possible with the current practices, it was (and is) essential to analyze the procedures and the possible benefits that the end users expect to obtain from the introduction of the new electronic system. In this phase, a round of interviews and workshops was carried out in order to find a common understanding of practices and methods. It was also necessary to analyze several aspects regarding the work during an MCI under extreme conditions: needs of the users, human factors, and technical requirements. The outcome of this process was a long list of formalized use cases, which were translated by the project partners into a requirements document.

Among several usability aspects key outcome was that the system has to fulfill the following general necessities:

(1) Scalability: The system must be able to assist rescue forces in a wide range of MCIs, considering on the one hand their size, and on the other hand, the geographical impact. Moreover, different types of organizations may be active on the disaster area. The system must assure inter-operability among the different forces.

(2) Dynamics: Rescue teams and their hand-held devices may join/leave the system at any point in time and space during the rescue operation. The system must support dynamics in order to manage late joins and users leaving the system.

(3) Ease of use: In a general case, the users of the system will be members of rescue forces with (normally) limited technical background. The system must be easy to deploy in the field and must provide a user-friendly interface in order to be operated under heavy stress.

(4) Security: Communication among members of the rescue teams and transmission of data about the victims must be done in a secure way in order to assure integrity and confidentiality of the data being transmitted. Moreover, use of the system (i.e. especially communication bandwidth) by non-authorized persons must be prevented.

(5) Reliability: If end users should use the e-Triage System instead of the paper-based one it is crucial to provide software reliability as well as technical reliability. This means that the software must be robust enough so that its operation is never interrupted regardless the network connectivity at every moment. The objective is that users feel safe using the system and their work is not interrupted.

B. Acceptance Research and First Trial

With the collected requirements a first implementation of the system was tested in a laboratory environment. In parallel to the implementation works, several meetings and reviews have been held in order to confirm users' expectations.

The project planning foresees altogether four trials with three of them focussing on specific aspects. The last trial scheduled for October 2011 will demonstrate the fully deployed system.

The main objective of the first trial in January 2011 was to evaluate the psychological acceptance of the system experienced by users with focus on the graphical user interface. For a comparison a realistic laboratory test simulating a disaster event, taking into account environmental variables like noise, darkness, extreme sun light and difficulty of movement, was prepared. Rescue teams performed the triage with and without using the system, and the corresponding reactions were analyzed measuring cortisol, peak expiratory flow, attention, work flow and communication under stress circumstances. Standardized questionnaires, such as KAB [2], Ergonomie [3], Technophobia Scale [4] and interviews analyzed with GABEK® WinRelan® [5] helped to evaluate the results.

Taking into account the feedback from end users obtained while performing the first realistic trial, several conclusions could be derived. The feedback of the people who used the e-Triage technology shows that they did not have problems while using the system and that they would like to use it for their regular work. The complexity of the graphical interface must be reduced and its design should be more intuitive. If the system should replace the paper-based version it should have more profoundness so that every victim and every involved person can be registered. The analysis of these conclusions leads to a new set of requirements or modifications of the previous ones in order to make the system closer to the end users' needs. This new set of requirements triggers a new cycle of re-design, implementation and testing, that will end up – after obtaining new impressions in the trials – in a newer set of requirements. This iterative process facilitates the identification of room for improvement by means of small and incremental refinements instead of large and complex modifications. Figure 1 shows a diagram of this iterative design and implementation process.

A major benefit for the project was the fact, that several staff members of the partners are actively involved in rescue organizations. The available expertise among the project team ranges from volunteer (and professional) medical rescue and firebrigade work via part-time work in rescue coordination centers to professional experience in critical incident stress management. This framework facilitated communication among project stakeholders a lot since from the beginning there was a good understanding of rescue professionals' needs.

III. The e-Triage Concept

e-Triage proposes a system for the electronic registration and management of victim data both for MCIs and regular rescue services. Considering an MCI as worst-case scenario, where the communication infrastructure, if ever existed, may have been destroyed or non-operative, the proposed solution provides the different rescue forces with a tool to coordinate and carry out necessary logistics. Apart from acceptance issues

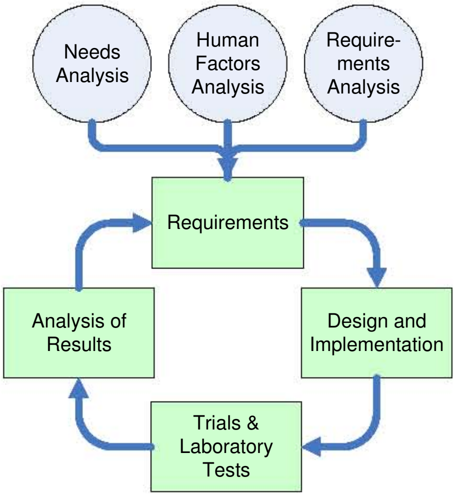

Fig. 1. Design and implementation iterative process.

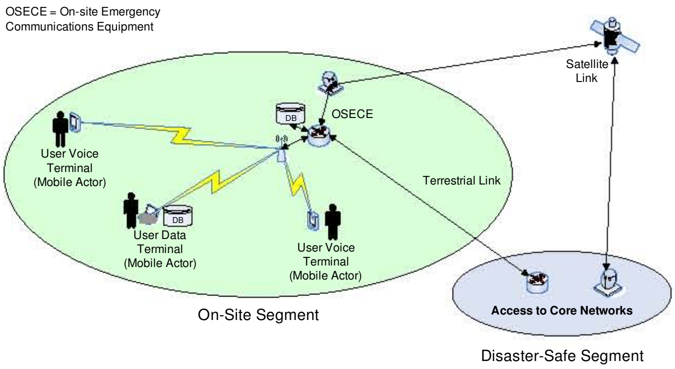

Fig. 2. Simplified e-Triage system overview for the MCI scenario.

the system is based on three previously stated technical areas: a robust and rapidly deployable satellite-based telecommunication infrastructure, ergonomic user interfaces, and automatic replication and dissemination of gathered data. This section describes the chosen approaches to fulfil the user requirements.

A. Communication

The e-Triage system is intended to provide robust communication both on the disaster area and also between the disaster area and any remote location. Therefore, in a general case, two different domains or areas can be defined: the on-site segment and the disaster-safe (off-site) segment. The on-site segment is the area affected directly by the disaster event, where the victims are located and the rescue teams work. The disaster-safe segment should be understood as a remote location not affected by the disaster event, from where personnel in a control center are able to coordinate the rescue process. Besides, the off-site segment provides access to core networks. A diagram of a simplified system architecture is depicted in Figure 2.

The severity of the event and the existing or remaining communication infrastructure triggers the usage of a variety of radio systems. Commercial GSM-based cell phone systems can be used, but these networks tend to get overloaded in abnormal situations. For rescue forces dedicated professional mobile radios (PMRs) systems are preferable, which range from analogue radio to Terrestrial Trunked Radio (TETRA) or TETRAPOL and are used during the first hours/days after a disaster event. Also satellite phones, such as Globalstar [6] and Iridium [7], might be necessary.

Fig. 3. Inmarsat BGAN version of the OSECE system.

The e-Triage communication system aims at integrating these terrestrial and long-haul (satellite) standards. There are other projects and products addressing the same objective; an overview can be found e.g., in [8]. Main difference to other approaches is that the different access technologies (GSM/GPRS, wireless local area network (WLAN), TETRA or Digital Enhanced Cordless Telecommunications (DECT)) are integrated in a single unit called on-site emergency communications equipment (OSECE), which is designed in two formats: as a compact and light-weight device only comprising GSM/GPRS and WLAN; and as a more robust solution including TETRA and DECT.

The small solution uses the Inmarsat BGAN system [9] for the backhaul link, and both aligning the satellite antenna and starting the system takes not more than 5 minutes. Everything fits into a small cabin-size suitcase [10]. Figure 3 shows the deployed suitcase solution based on Inmarsat BGAN (satellite antenna in the front).

Although the Inmarsat BGAN satellite link only offers capacity of 256 and 128 kb/s in the forward and return link, respectively, it is enough to satisfy the communication needs identified for the early phase after a disaster event using GSM/GPRS and WLAN as terrestrial access technologies. For a later phase, a bulkier version of the system has been developed using a self-aligning very small aperture terminal (VSAT) antenna. This version of the system offers more satellite link bandwidth, but requires adequate transport means. It deploys TETRA and DECT also, which are technologies widely used by rescue forces.

All data is transmitted over the satellite link, independently of the access technology. In each OSECE an Asterisk [11] voice server is installed in order to distribute the calls and convert them to standard Voice over IP (VoIP) if they are to be transmitted over the satellite.

In satellite links, bandwidth is a scarce and expensive resource, so means of compressing and multiplexing the transmitted data have been implemented, mainly for voice traffic, where the headers of transmitted packets are bigger than the actual voice data payload. This software allows 11 parallel calls through a 64 kb/s link using the adaptive multirate (AMR) 4.75 kb/s codec. A way to send efficiently the database updates through the satellite link is subject to further investigation.

All communication points, independent of the technologies deployed, are connected to each other, forming a large network which is completely transparent to users. With this architecture, the system can be adapted to each use case from small incident to supra-regional disaster. In order to support Global System for Mobile Communications (GSM) roaming in the field, all base transceiver stations (BTSs) have to belong to the same core network (base station controller (BSC), main switching center (MSC), home location register (HLR), . . .).

WLAN access points need to coordinate themselves automatically. There are several approaches possible, one of them is based on ad-hoc networks, considering the access points both as ad-hoc elements and servers for the end devices. An example of this has been described in [12]. However, in the e-Triage network it has not been tested yet and alternatives are still being investigated.

B. Data Gathering

Apart from the communication capabilities, user-friendly gathering and presentation of patient data is one of the major pillars of the e-Triage concept. Collecting triage data may not be hindering, and presentation to decision makers has to take place in a clear and understandable manner.

As explained before, state-of-the-art of this process is paper: cardboard triage tags are hung around the patients' necks, and summaries are transmitted to a control center using voice-based radio. This way of operating is rather slow and error-prone. Electronic registration overcomes these drawbacks since data is transmitted electronically avoiding loss, duplication or inaccuracy of information.

In order to satisfy the user requirements and to provide a system which adapts to the current practices without introducing additional stress to rescue forces, both hardware and software issues have been taken into account. The main requirements regarding the hardware to be used were:

- Robustness;
- Display readability in direct sunlight;
- Pen-operated touchscreen;
- Dual-battery concept for uninterrupted operation;
- Built-in WLAN, general packet radio service (GPRS), Universal Mobile Telecommunications System (UMTS), and Bluetooth;
- Built-in camera, radio-frequency identification (RFID) reader and 2D-barcode reader;

Fig. 4. Tablet-PC and graphical user interface.

- Built-in GPS.

Small devices like smart-phones and personal digital assistants (PDAs) were not taken into account because they are not suitable for filling in detailed emergency physician documentation for regular emergency medical services. In a workshop several commercially available tablet-PCs, pre-selected according to the technical requirements, were presented to users. Every user tested all tablet-PCs and Think Aloud Protocols [13] were developed and analyzed by GABEK® WinRelan®. One model fulfilled the most quoted aspects. These aspects were compared with the needs, human factors and requirement analysis and finally this model was selected.

The software architecture of the end device consists of three main parts: the user interface, the local database instance, and the communication unit [14]. By grouping the functional entities application/database and database/network the user has a maximum of application performance by writing his data directly into the local database. An intuitive and self-explaining user interface has been developed which maps current triage procedures into a user guidance system.

Role management and security features, such as data encryption and restricted access, are also provided by the system. Acceptance of the system by end users has been analyzed during the first system trials hold in Starnberg (Germany) in January 2011. Figure 4 shows the selected Tablet-PC using the developed graphical user interface to introduce patient data while reading the bar-code of the cardboard triage tag.

C. Data Management and Replication

The third main component of the e-Triage system deals with the proper management and dissemination of the collected data by using a completely distributed database system [15]. Gathered data is stored in local databases installed in the tablet-PCs (mobile nodes) and if there is network connectivity forwarded to fixed databases attached to the OSECEs (fixed nodes). All data management operations are performed in an automatic way in the background, so that members of the rescue teams do not have to carry out any related task or provide any input [16].

Data from a mobile node is forwarded to the corresponding database in the serving OSECE. Since more than one OSECE can be deployed in the field, the database in the OSECE must forward the information to other OSECEs and also to remote database servers. Then in turn, each OSECE must forward the received data to any other tablet-PC connected to it, so that all database nodes connected to the system share the same information. Key advantages of this approach are (i) there is no single point of failure, (ii) in case there is no connectivity between OSECEs a mobile node can be used to exchange data between the OSECEs, and (iii) network interruptions are built-in design aspect.

As the proposed solution uses a distributed database system, the basic atomicity, consistency, isolation, durability (ACID) properties must be assured. Normally, when mobile nodes are connected to the corresponding fixed node with a stable network connection, an existing replicator system is used in order to forward changes in the database as soon as they are produced. In case of connection interruption between the mobile and the fixed nodes, both nodes work independently and synchronize themselves as soon as connection is re-established.

Apart from basic data replication and synchronization, the system performs also data prioritization in order to adapt the data to be sent to the capacity of the links. This way, for instance, only data with high priority will be sent over the wireless link in case of congestion, delaying the transmission of the remaining data to a moment of lower occupation of the link.

IV. Conclusion

An IT-supported patient management system both for regular emergency services and for MCIs is the overall objective of the e-Triage project. This paper has briefly discussed the process to derive end-users' requirements and to integrate them into a sound technical concept.

MCIs are in their first phase always chaotic and confusing. Technology can help to overcome communication deficiencies so that all levels of decision making have access to the same information at the same time. A tailor-made design of the graphical interfaces supports users to follow the intended and trained work-flow. For design and implementation of the system, an integrated working approach has been performed at all development stages by engineers, software specialists, computer and information scientists and psychologists. An iterative approach has been considered in order to assure success by developing a system as close as possible to users' requirements, testing the system in realistic conditions.

Anticipating outages and failures of network elements (routers, wireless links, tablet-PCs) is mandatory for disaster management systems. Applications have to remain functional also in provisional environments which includes unstable or highly loaded networks. Besides users may not be bothered with configuration works, since this can be very time-consuming and might increase the stress level. In fact, time wasted for fiddling around with IT-systems is time lost for patient care.

The e-Triage project team plans a final trial of the full system in the region of Munich in October 2011.

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