Interactive Cognitive Artifacts for Enhancing Situation Awareness of Incident Commanders in Mass Casualty Incidents

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ABSTRACT
In mass casualty incidents (MCIs), incident commanders are responsible for managing operations, guiding rescue forces and applying resources appropriately. Data required for situation assessment and decision making are gathered and shared by numerous face-to-face talks, radio calls and paper-based forms. These tools and means of communication support flexible modes of operation but often lead to deficient awareness of the situation. Information sharing in the field is hampered and delayed. Interactive cognitive artifacts might improve the situations compared to using established paper-based artifacts by exchanging and visualizing data in real-time. However, because of users' workload and working conditions, designing mobile computer-based tools and systems for this context of use is a usability challenge. Based on the results of a two-year user-centered system design project with Emergency Medical Services, we discuss currently used and interactive cognitive artifacts for incident commanders. Challenges and approaches to successful user interface and interaction design are described.

Author Keywords
Cognitive Artifacts, Situation Awareness, Mass Casualty Incident, Incident Command, Usability, Interaction Design

ACM Classification Keywords
H.5.2 User Interfaces; H.1.2 User/Machine Systems; H.5.m Miscellaneous

INTRODUCTION

In general terms, Emergency Medical Services (EMS) are *"[...] the ambulance services component that responds to the scene of a medical or surgical emergency, stabilizes the victim of a sudden illness or injury by providing emergency medical treatment at the scene and transports the patient to a medical facility for definitive treatment"* [20]. Regular medical transport or emergency missions with one or few patients need to be distinguished from those with larger number of patients. Due to the mismatch between patients and first responders they require adapted tactics and workflows.

Incident commanders, e.g. chief emergency physician or ambulance incident officer, are responsible for various aspects of command and control (see Figure 1). They have to prioritize tasks, apply medical and logistical resources efficiently and lead subordinated paramedics and physicians in exceptional arrangements.

Figure 1: Chief Emergency Physician ("Leitender Notarzt") and Ambulance Incident Officer ("Org.-Leiter") assessing the triage area during an MCI exercise in Germany

For them, *"knowing what is going on around you"* [6] is not possible by only direct perception and interpretation of events. Usually, circumstances are too complex and dynamic. Many important elements might be out of sight, range or mind. What matters most are

- a steady flow of information between incident command and operational units,
- usable tools and aids for information management.

BACKGROUND AND RELATED WORK

In the following sections, mass casualty incidents are characterized briefly. Then, this context of use is related to situation awareness and cognitive artifacts. Finally, established equipment which is currently in use by incident commanders in Germany will be described.

Our findings are based on observation of two EMS exercises in different federal states, five workshops with EMS employees and several interviews with incident commanders. They were part of a two-year user-centered system design project with EMS. The project resulted in an advanced prototype of an information system for mass casualty incidents (MCIs) which has undergone formative and summative evaluations [12, 13, 14].

Mass Casualty Incidents

Train accidents, airplane crashes or terrorist attacks often result in publicly recognized MCIs. Nevertheless, minor events can generate *"more patients at one time than locally available resources can manage using routine procedures"* [19], too. Contributing problematic causes could be time of occurrence (e.g. at night), location of accident (e.g. freeway, poorly accessible areas), weather conditions (e.g. heavy rain, snow), and utilization of responsible EMS (e.g. while being in charge of other events at the same time).

While all involved paramedics and emergency physicians have to adapt treatment strategies and other operating principles, incident commanders have to deal with questions of leadership and organization. Five essential ranges of tasks can be distinguished [16]:

- tactics,
- triage,
- treatment,
- taking care,
- transport.

Triage, i.e. efficiently determining severities of injuries and prioritizing treatments, is regarded to be the most important task directly following basic life support actions [17]. It implies an order in which casualties are transferred from triage to transport. The process should be supervised by the chief emergency physician and supported by the ambulance incident officer. Both are responsible for organizing and running triage, treatment, and transport areas.

Situation Awareness in MCIs

Situation awareness (SA) can be defined as *"the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future"* [5]. It has been repeatedly identified as a major concern in domains like aviation, traffic control, power plant operation and defense. However, it gains increasingly importance with respect to pre-hospital medical care [2, 3, 4, 9]. In the context of MCIs, it is both important to ensure well-arranged courses of action and a demanding challenge:

- *Perceiving* environmental elements is affected by their spatial distribution and permanent movement (e.g. arriving and departing ambulances).
- *Comprehending* their meaning is complicated by disturbances and various stressors (e.g. noise, number of casualties, conflicts of competence).
- *Projecting* the future is limited by suddenly changing settings (e.g. physical condition of casualties) and occupied cognitive resources (e.g. by making decisions).

Tools and aids for record keeping and information management should support incident commanders' work and decrease their workload.

Cognitive Artifacts in MCIs

Cognitive artifacts can be defined as *"artificial devices that maintain, display, or operate upon information in order to and suitable serve a representational function and that affect human cognitive performance"* [15]. On different levels of abstraction, they represent entities and relationships which are of peculiar interest in a specific domain [11]. With regard to MCIs, these are patients and their medical conditions as well as available medical resources (e.g. vehicles, physicians, utilization of hospitals).

Cognitive artifacts are meant to support and ease human problem solving as well as accelerate and improve task completion. From a personal view, introducing or modifying cognitive artifacts changes the way how people accomplish tasks and how cooperation will be conducted [15]. Incident commanders have been skilled in different topics (e.g. emergency medicine, command and control) but they are different from operators of other complex socio-technical systems in some respect. First of all, they don't perform supervisory control on a daily basis. Crews for regular missions consist of 2-3 persons and work together as well-matched teams. Secondly, although applying sophisticated medical technologies regularly, they are not used to interactive and multimodal human-machine interfaces in everyday professional life.

Cognitive artifacts represent *"a meeting point […] between an 'inner' environment, the substance and organization of the artifact itself, and an 'outer' environment, the surroundings in which it operates"* [18]. In terms of EMS employees' working conditions, the latter can hardly be planned ahead because MCIs can occur anywhere and anytime. In spite of that, they are rare events for a specific incident commander (cf. [1] for an exemplary analysis of a German district). Therefore, cognitive artifacts in this safety- and time-critical domain have to be suitable for the task, self-descriptive and conform to user expectations. Learning and adaption phases have to be avoided respectively minimized.

Cognitive Artifacts for Enhancing SA in MCIs

Currently, incident commanders mainly use paper-based cognitive artifacts. Forms and tables, maps and charts, and private notes can be distinguished and are covered below. In general, the selected examples of German EMS are similar to the ones in other countries.

Forms and Tables

Dedicated documentation and information systems have been developed in preparation for MCIs. They consist of various forms, which are suitable for certain areas or phases of a mission. While some of them are commercially available, others have been introduced by EMS on their own. Figure 2 shows a table with columns for patients' identifiers, names, triage categories and diagnoses. Most entries were added by handwriting. Identifiers were taken of triage tags and affixed to the form. There is a mismatch between row and tag sizes. It complicates clear assignments and readability. Such problems related to layout, color contrast and overall design of artifacts are no exception.

Figure 2: Summary of patient data

Typically there will be templates for

- summarizing time and result of each patient's triage at the triage area;
- documenting actions at the treatment area(s);
- registering transport decisions at the staging area (e.g. vehicle identifier, patient, destination, departure time);
- recording hospital assignments in order to ensure balanced distribution;
- organizing the assembly area (e.g. arrival and departure);
- enabling quality management by consolidating data from different sources.

In addition to such mainly textual and tabular representations, graphical notations are established as well.

Charts and Maps

For visualizing organizational structures or spatial relations, maps and charts are used by incident commanders. While some of them can be carried around (see Figure 3), others are fixed at a command vehicle. Magnets or tactical signs can be applied to some of them for showing recent developments in the field. Several maps are necessary for different resolutions (e.g. vicinity, proximity, buildings) and aspects (e.g. topography, infrastructure).

Figure 3: Incident commander holding a chart and a radio

Apart from using templates and published material, many incident commanders record certain data in their own way.

Private Notes

Some of these sheets of paper are prepared in advance, e.g. by dividing sections or listing keywords. Others are initially blank and structured on the fly (see Figure 4). Most of them are used for short-term memorization. Sometimes they are left behind after just a few minutes of usage without referring to the notes again during the operation.

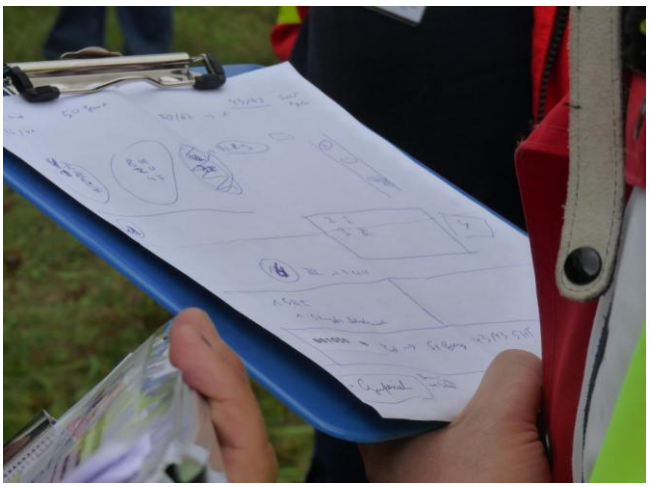

Figure 4: Incident commander looking at notes

INTERACTIVE COGNTIVE ARTIFACTS

While the previously mentioned artifacts can be considered to be the status quo, they will likely be replaced or complemented by pervasive computer-based solutions in the future. Advances in the development of rugged mobile devices, wireless internet access and ad-hoc networking as well as a changed perception of the overall safety situation in the western world led to increased research and development. Prototypes have already been tested in the field and particularly proven to work with respect to technical or infrastructural requirements (e.g. [4]). Some of them process and visualize a wide range of information, e.g. patients' conditions, hospital assignments, or chronology (see Figure 5).

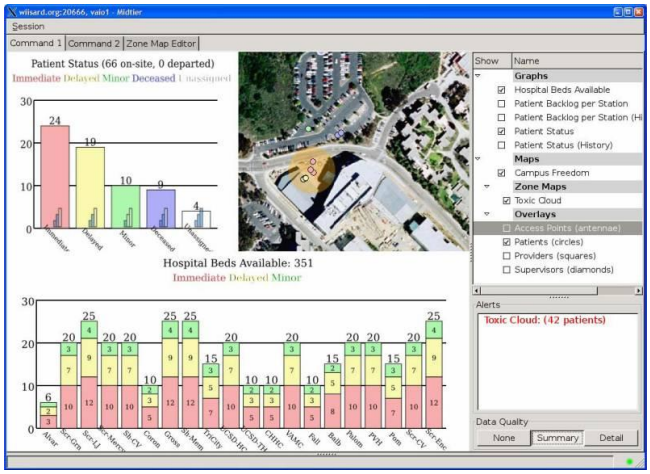

Figure 5: The WIISARD command center display [4]

Questions of usability in this domain are rarely related to cognitive ergonomics, task analysis, human-computer interaction, and design (e.g. [4]). Following some more general remarks to usable computer-based solutions in MCI management, challenges and approaches to cognitive ergonomic design of interactive tables, maps and note-taking are considered.

General Remarks to Usability

Developing interactive cognitive artifacts for the context of pre-hospital medical care is a challenge for various reasons. Interface and interaction should be designed iteratively and by user participation. However, short-term scheduling is complicated by work schedules and staff requirements.

Field studies and test runs can hardly be projected. Workshops, interviews and expert reviews often take place in conference facilities or office rooms. Such favorable conditions differ completely from the real context of use. Thus, interruptions and other performance-disturbing factors that characterize MCIs have to be considered specifically and carefully. What seems like an appropriate approach in a relaxed training situation might be a hardly manageable case of information overload in the field. Furthermore, computer-based tools and systems are an additional medium of communication and channel of information. They have to be aligned with established workflows and organizational structures which depend on thorough exchange of radio messages.

MCIs are rare events for single EMS employees. Practice in efficient and safe handling and operating interactive cognitive artifacts cannot be ensured by exercises or training courses. It can only be derived from intense and regular application. A rugged tablet PC (see Figure 6) with support for pen input can be considered an appropriate hardware approach to a consistent user interface for regular and extraordinary missions. We have basically confirmed this in formative and summative evaluations based on a prototypical application [13, 14].

Figure 6: Rugged tablet PC displaying the distribution of triage categories as a bar chart

Although striving for consistency, certain screen layouts and interaction elements, according to MCI management, would not be used by incident commanders in daily duty. Well-established design principles (e.g. [8]) should be considered while dealing with well-known design issues especially for these parts. Obviously, it is necessary to apply these best practices to the specific context of MCIs [17]. As they represent essential entities and relationships, currently used cognitive artifacts might be an appropriate starting point for this process.

In safety- and time-critical domains with highly skilled personnel, it seems advisable to build upon experiences. Furthermore, questions of automation, adaption, and individualization arise with respect to division of tasks between human and machine. User interface and interaction have to be designed with respect to hardware capabilities (e.g. screen size, resolution, input and output modalities) and context.

Challenges and Approaches to Ergonomic Design

As mentioned before, incident commanders currently take private notes and work with various paper-based documents in order to enhance their SA. Some of them are stationary and others have to be delivered manually. They can be arranged, sorted, or marked by the user to a limited extend. Computer-based tools would allow data access and exchange near real-time and from remote but offer only limited screen space. Feedback about incoming data must be given explicitly.

Forms and Tables

With respect to forms and tables, some major challenges are

- efficient navigation between different sections;
- usable visualization of larger datasets;
- efficient browsing of numerous datasets.

Tabs, i.e. multiple screen masks within a single container and a navigational widget, can be used to group single tables logically and ease access. Another approach is to mark an item in one table and see the links to related items in other forms.

Larger datasets might not be presentable in a single table row. Two possible approaches would be folding out entries on demand or displaying detailed data of a marked entry in an overlay panel. Search options have to be available and should support phonetic search. Activated filters must be clearly visible, otherwise, the subset of displayed datasets could be perceived as the total set. Temporarily marking favorites, e.g. in terms of patients to remember, can be a feature to relieve incident commanders' working memory.

With respect to navigation, paging and continuous scrolling are two basic options. While the latter one is the most prevalent at mobile devices in general, we observed some difficulties with pen-enabled devices. Some users slipped of the surface. Such difficulties could increase stress levels. Therefore, we would recommend implementing a more fail-safe paging solution – at least in addition to the other one.

Charts and Maps

The number of patients in specific triage category is one of the most important pieces of information for incident commanders. In addition to tabular or textual visualizations, bar charts can be an appropriate design solution. During our workshops we presented four drafts differing in the number of categories and labeling (see Figure 7) to 36 EMS employees. We asked for their favorite or a self-created version. While 2 responses were ambiguous, 34 could be evaluated. The 3 most preferred versions got 9, 6 and 5 votes, respectively. 5 participants created their own solution. Allowing for minor modifications, e.g. position of labels, one version got 14 votes. The drafts were subject of controversial discussion. They enabled us to better match our conceptual with their mental model beyond the use cases associated with the actual chart.

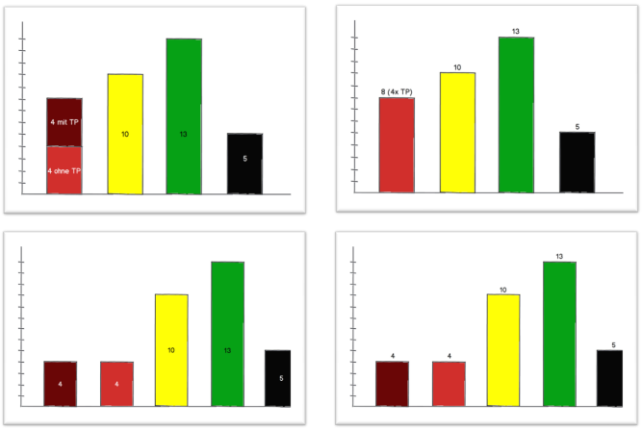

Figure 7: Alternative designs of a triage categories bar chart

Using location-based services by tracking casualties, EMS employees or vehicles and visualizing them on maps looks promising but raises issues of reliability. Both tracking inaccuracies (e.g. in buildings, under bridges) and loss or removal of locatable items (e.g. by casualties in a state of shock) could result in inaccurate data. Such date would be worse than none at all. More or less stationary information (e.g. territorial allocation of operation areas) can be represented more reliable (see Figure 8).

Figure 8: Situation Map with tactical signs

Data exchange with geographic information systems in emergency control rooms or command vehicles might be mandatory. Moreover, some incident commanders and EMS managers expressed reservations about modifying situation maps by multiple actors. They were strongly in favor of a read-only mode for workers in the field.

Personal Notes

Personal note-taking should always be possible and could be realized easily on a pen-enabled tablet PC. A digital notepad within reach of every screen mask would be a first step. It should support both handwriting recognition and freehand drawing. Advanced solutions could offer more shortcuts, e.g. for creating tables or marking entries in different colors.

CONCLUSION AND FUTURE WORK

Due to several cognitive and emotional factors, MCIs are an extraordinary challenge, even for experienced emergency physicians and paramedics. SA is of the utmost importance for incident commanders. They are responsible for best possible treatment of patients and workload of EMS employees. Interactive cognitive artifacts can support their demanding work and improve on established equipment. However, the design and usability of the artifacts is an interdisciplinary challenge. Participatory design has to be conducted right up to detailed user interface and interaction design solutions. Users might only have little time to perceive and comprehend visualizations or be disrupted meanwhile. Matching mental, conceptual and technical models are required to minimize mental workload, ease decision-making and ensure performance in the field.

The Chief Emergency Physician or the Ambulance Incident Officer have to form teams. Therefore, future works should not just consider individual SA, but Team and Shared SA in order to further enhancing usability of interactive cognitive artifacts and cooperation possibilities [7].

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