GIS-based Information Distribution in Emergency Management

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Abstract

Availability, distribution, and comprehensibility of information in emergency situations are preconditions for decision making and emergency response. Concise distribution of available information is especially vital for mobile environments, where bandwidth is a scarce source. In addition, time-critical domains, such as emergency management, demand fast decisions from expert users under stress. The Decision-centered visualization (DCV) approach supports decision making by integrating domain knowledge and knowledge about human situation awareness for time-critical information distribution. Efficient GIS information presentation is vital for the user's situation awareness and, in consequence, to task performance in emergency situations.

1 Introduction

Availability, distribution and comprehensibility of information in case of emergency are basic preconditions for decision making and responding to exceptional circumstances. A prediction of emergencies is usually not possible - when and where it will happen is unknown. This means, it is necessary to distribute available information in an emergency quickly into different technical environments for different decision makers. These environments include members of the technical management that have direct access to the information, web clients that allow participation of the public or remote access by the strategic management in a ministry. They also include mobile clients that allow access to vital information by task forces and decision makers in the field, support task forces from other regions in finding the right location, and alert absent decision makers of emergency situations.

"Time is money" is one of the slogans of today's world. Many applications – even in the world of spatial related data – became time-critical in the past. GIS (geographic information systems), as the core of complex geographic support systems for time-critical decisions, can be used for integrating the available data, using their spatial relationship, make them available for other processes, and visualize them in an intuitive way. In the past, GIS have often been used as desktop visualisation systems for spatial data. In recent years though, supported by the increasing importance of networking environments, web-GIS and distributed information systems became increasingly important. Today's research especially focuses on mobile and 3D information systems. To overcome the technical problems coming from several formats and interfaces the Open GIS Consortium (OGC) works on standardization in these areas. In consequence, GIS became increasingly important in time-critical applications, especially in emergency management.

Addressing the outlined requirements and research trends, this paper introduces an information system approach taking into account the several different decision makers in emergency management, their tasks, backgrounds, and the technical environment they work with. Based on geographic information – as usual in emergency management – this system visualizes the information in geographic context. The decision-centered visualization (DCV) approach plays a vital role in this effort by providing filtering and prioritization of information depending on the current emergency situation, the task the user is working on, and the role of the user in the current task. Wherever possible, 3D maps are used as visualization, while 2D maps and textual descriptions are used for appropriate environments.

2 Information systems in time-critical environments

Users of information systems in time-critical situations that are common in emergency management are under pressure to digest and process information that is vital for their task. Thus, the user needs efficient information visualization that avoids displaying information that is not vital at the moment. Decision-centered visualization is an adaptive visualization technology that supports decision making by integrating domain knowledge and knowledge about human decision making with interactive visualization architecture for mobile and general network environments. Decision and task models, and knowledge of the information environment of the application domain, are all tightly-coupled with the human-machine interface and the visualization architecture in order to produce timely, knowledge-based presentations. The objective is to provide knowledge-based visualization components that enable decision-makers to quickly achieve situation awareness during their tasks, and to make informed decisions under time pressure.

2.1 Situation Awareness

Situation Awareness (SA) can be described as the human user's internal conceptualization of a situation. A formal definition by Endsley [4] defines three levels of SA: the perception of the elements in the environment within a volume of time and space (Level 1), the comprehension of their meaning (Level 2), and the projection of their status in the future (Level 3). Endsley's SA model, a prominent theory related to naturalistic decision making, is depicted in figure 1.

Situation awareness involves far more than simply perceiving information in the environment. It includes comprehending the meaning of that information in an integrated form compared to one's goals, and providing projected future states of the environment. These higher levels of situation awareness are particularly critical for effective decision-making in many environments.

Each level in Endsley's model builds upon the previous level. Thus, a system has to store and provide access to information on the essential elements in the current environment (Level 1) to be able to support the human user's perception of the current situation (Level 2). Information that is relevant to the decision-maker's task supports the user's situation awareness (SA). Enhancing the user's SA, in consequence, results in a higher probability of good decisions and successful task performance. Our goal was to build a system that visualizes information tailored to the SA requirements of the user.

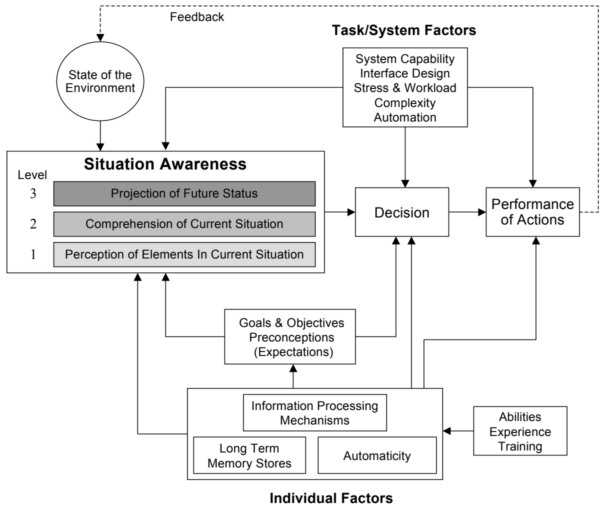

Figure 1: Model of Situation Awareness in Dynamic Decision-Making [4]

It should be noted that there are several other human factors models, especially in the field of naturalistic decision-making [1], [9]. In particular, Klein [6] worked extensively on providing models that describe cognitive processes and decision making of firefighters and other emergency managers in stressful situations.

2.2 Decision-centered visualization

DCV embodies a distinct and unique view on decision support – DCV is not intended to replace human decision makers, to automate diagnosis or planning, or to provide expert advice to human problem solvers. Instead, DCV is focused on real-time, context-sensitive, interactive visualization. As a visualization system, DCV uses domain, task and decision knowledge to assure that decision makers are presented with the right information at the right time.

DCV embodies the argument that this can only be done by merging knowledge technologies with interactive visualization. By using information about current tasks and the concise presentation of task-relevant information, the decision focus

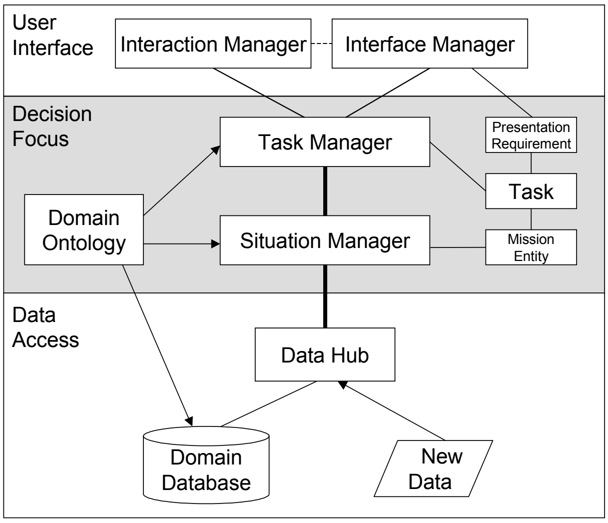

Figure 2: The DCV Architecture [7]

module aims at avoiding information overload. While the decision focus module decides what needs to be displayed depending on the user's task and situation, the user interface module chooses an appropriate information presentation based on the current interaction mode and the priority of the information. The Interface Manager maintains the current state of the presentations, supervises the overall appearance, and modulates modifications of the current presentation.

The DCV architecture is divided into three main parts (see figure 2): The data access module, the decision focus module, and the user interface module. The central decision focus module tracks and controls information about the current situation and the tasks and decisions being worked. The domain ontology and presentation requirements are integrated with the decision focus module to show information relevant to a particular situation, task, and user in the DCV system.

The domain ontology contains the types of objects, processes, and events within the application domain. For example, in the emergency management domain, the Domain Ontology might contain a generalization hierarchy that defines a medical evacuation helicopter as a kind of aerial transport. The ontology represents these kinds of hierarchical relationships and also defines a uniform language for the domain. The instances of the concepts and object types in the ontology are stored in relational databases. For more details on the ontology mechanisms involved in DCV see [8].

All databases and incoming data streams are processed by the data access module, while interface manager and interaction manager are responsible for the user interface functionality. The user interface is device-independent, and is not tied to a particular rendering engine, but instead, gives suggestions and commands to the visualization system based on an API.

2.3 DCV for emergency management

An information system incorporating DCV for emergency management can utilize information and knowledge of the emergency management domain to display to the user of the system filtered information specific to the current task, e.g. the time-critical analysis of a train accident. To support this analysis, information is embedded in maps or 3D terrains, to make the context of the information apparent.

Recent advances in the technology infrastructure bring a variety of new applications to emergency management. The technology involves powerful portable computers, digital telephones, satellite imaging and sensors, environmental sensors, networks, both line and wire-less. It includes remote sensing for data collection and geo-positioning devices for pinpointing locations (shelters, incidents, facilities, schools, hospitals, nursing homes, schools) and wire line and wireless networks. Future research in the technology infrastructure will continue to increase the capacity of the emergency management system. Technology can bring to the emergency management community an intelligent assistant for enhancing decision-making. Nevertheless, DCV does not intend to replace individual discretion and decision-making but serve as a tool for task and decision support.

Critical information is now more available to emergency managers as a result of our expanding networks. Some sensors provide real time access to data. As an illustration, the U. S. Geological Survey has installed a system of stream monitoring gauges to provide timely information on water levels in streams and rivers. Sensors are installed in the streams and rivers and available over networks remotely to the emergency manager. More widespread use of sensors will allow emergency managers greater access to valuable inputs for decision support systems. The increasing attention to technology may inadvertently result in information overload.

In fact, time-critical domains are often dynamic and rich information environments, which tend to overwhelm the decision maker. This may result in high levels of stress and workload and increases the probability of missing cues and misinterpreting available information. Systems in time-critical domains involving a human agent are primarily constrained by the human processing capacity rather than the machine processing power. Since the human processing capacity remains constant, the only viable way is to support the human through efficient information visualization.

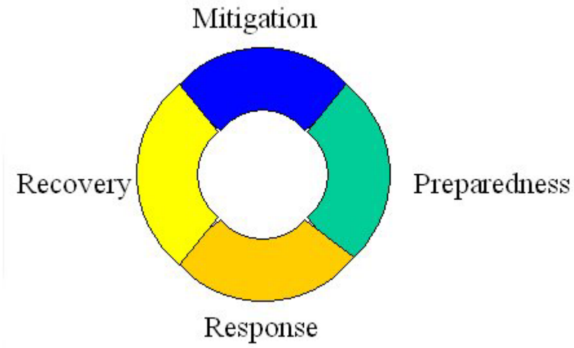

Figure 3: Four phases model in emergency management (FEMA) [5]

3 GIS-based information distribution

The use of distributed information systems allows its users to access data and services from providers that guarantee the accuracy and quality (e.g., timeliness) of data. Thus, it is not necessary anymore to store all potentially useful data in the local system. 3D geo-information and mobile systems are two domains for time-critical applications. On the one hand, the time necessary for searching, transmitting and analysing the data itself can be decreased, on the other hand the quality of visualisation can be enhanced to decrease the time a user needs to understand the displayed information.

3.1 User requirements

To find the requirements for a useful support system for decision makers in emergency management, it is necessary to know how to describe and characterize emergency management itself, to see what processes and decisions are already supported by geographic information, and to take into account current developments of GI Systems .

The Federal Emergency Management Agency (FEMA) divides emergency management into four phases defined as:

I. Mitigation: Reduction of the probability of occurring an emergency and the prospective consequences
II. Preparedness: Active preparation on a occurring emergency, training
III. Response: Acute phase after occurring on a emergency
IV. Recovery: Phase after the acute emergency including all arrangements to remove the arose detriments and for the long-term supply of irreversible detriments

In any of these phases technical and GIS support can be useful or is already in use [5]. Today there are many solutions for special scenarios and special phases of emergency management. Especially systems to support decision makers in the phases of mitigation, preparedness, and recovery are in use today. Examples for this are GIS-based flood simulations and the use of the calculated results in further planning. Results of such simulations can be used to predict the risk and the potentially quantum of damages (Phase I). But they are also necessary to develop useful and realistic scenarios to be used in trainings (Phase II). In Phase IV there is often a high public and political interest to see a situation before and after an emergency and to set priorities for rebuilding.

The number of systems for technical support in Phase III is significantly lower. Here emergency management is usual done with maps that are rarely digital. Useful systems to support decision makers in all of the phases are almost missing completely.

Seeing this situation in technical support of emergency management and knowing about the need for such support, GIS based support for decision makers comes more and more into focus. So an overall concept is necessary taking the new developments into account and delivering the information to the several decision makers in their several technical environments and responsible for different tasks.

3.2 Technical environment

Figure 4 shows the technical environment that has to be taken into account. GIS are mainly responsible for managing the data and have to serve several clients. Systems and applications that have direct access to the data are for example used for technical management. Remote clients give the information to political and strategic management. Mobile clients include mobile task forces and decision makers in the field. Finally, distribution of information by using a WebGIS incorporates media and public issues into the information system. It is, furthermore, necessary to give the geo information to several tools and systems like decision support systems and simulations that do not mainly focus on the visualization of data.

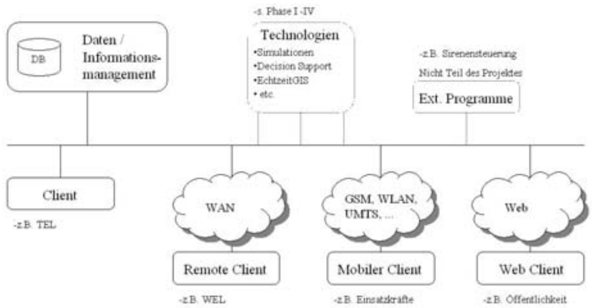

Figure 4: Technical environment in GIS-based support systems for emergency management [5]

3.3 Mobile GIS for time-critical applications

The recognition of and reaction to exceptional cases especially in disaster and emergency management is a challenge for decision makers who must be trained to be prepared to these situations. Nevertheless the quality of every decision depends on the available information on the basis of which the decision must be made. Furthermore it often happens that emergency situations arise just when the decision makers are not at hand.

In order to enhance the availability and topicality of the data relevant to the disaster and emergency management und to support the decision makers in finding the „right“ decision the Graphic Information Systems department is presently developing solutions for the use of mobile Geographic Information Systems (GIS) in this field of application. These systems enable the decision makers to access the actually available data from wherever they are, they support the communication between the different decision levels and accelerate the integration of current data.

3.3.1 Mobile Information Provision

The presentation of the information about the current situation on mobile devices enables task forces and their heads to get an impression of the situation and, especially, of their own environment independently of their actual position. The coordination and transmission of action orders between the disaster management headquarters and the task forces can be extended by graphic information in order to avoid lengthy explications and possible communication flaws. Non-local staff may use a navigation support to get quickly and securely to the operational area. The systems offer both the possibility to present the information as a map and to access additional information like text.

3.3.2 Mobile Data Acquisition

Besides the mere supply of information in the field mobile GIS applications are realized which support the recording and supplementation of data for the task forces (e.g. survey teams) and make these automatically available to the headquarters. These applications are conceived as Location-based Services, i.e. the task forces first get the available information about their current position and can verify or supplement it after measurement or observation. The modified data are then returned – together with a position entry – and integrated into the central data. The spatial relation of the information is maintained during integration into the data stock. In this way it is possible to reuse the data for further purposes.

4 Conclusion and Future Work

Geographic information systems have to be merged with filtering and prioritization tools for information systems in time-critical applications like emergency management. The lack of time to digest information by the user and the need for quick dissemination of information once an emergency occurs requires knowledge representation within the information system, to be able to decide about the importance of information during runtime. This approach aims at concise communication of quality information to mobile and non-mobile users and agents in the information network.

The combination of mobile GIS and task- and user-oriented prioritization and filtering through the DCV approach follows demands for user-centered systems in emergency management that take human factors into account [2]. Especially the recent advance in mobile computing technologies and higher bandwidth mobile communication suggest interesting future mobile applications in the emergency management domain.

The next step in the development of our technological approach is to further integrate the domain-dependent prioritization and filtering techniques with COTS (commercial off the shelf) GIS technologies. This will allow the many users of these GIS products to plug-in the described enhanced services for emergency management in mobile environments.

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