Decision Support for the Members of an Emergency Operation Centre after an Earthquake

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ABSTRACT

The first three days after an earthquake disaster demand good decisions in a very complex environment. Members of emergency operation centres (EOC) have to make decisions with limited information and under high time pressure. But the first 72 hours of disaster response activities are essential to minimize loss of life. Within the interdisciplinary German Collaborative Research Center 461: "Strong Earthquakes: A Challenge for Geosciences and Civil Engineering" a so-called Disaster Management Tool (DMT) is under development which presents some ideas for appropriate solutions to this problem. One module of the DMT will provide decision-support for the members of an EOC based on the Recognition-Primed Decision (RPD) model, a description of the decision-making process of persons in real-world settings. Options for a reasonable computer-based decision support for the RPD process will be discussed. For this the system combines a simulation of the disaster environment with a multi-agent system (MAS). The simulation shows the results of different decisions so the decision-makers can evaluate them. The MAS calculates a solution for optimal resource allocation taking into account current available information. The goal of the ongoing work is to integrate these instruments into a user-friendly interface considering the real life needs of decision-makers in an EOC.

Keywords

Decision support, human computer interaction, emergency operation centre, RPD model.

INTRODUCTION

When urban areas are stricken by earthquake disasters and experience substantial destruction, disaster response teams are often overstrained with the typical course of events. An efficient and integrated disaster management by the members of an emergency operation centre (EOC) could support their activities and help to limit human losses. But EOC personnel has to face own problems. In most cases decision-makers rarely have experience with such events, as these do not occur frequently. Due to information overload EOC members are barley able to process incoming information and they also have to coordinate their activities with other decision cells. Besides this there are not enough resources to cope with the impact of the disaster. Decision makers have to ponder where to send their available resources to get the best results, meaning the highest possibility to save human lives.

There are different ways to improve the decision making of EOC members in disaster situations: (1) Enhancing the communication and information distribution; (2) Provide help with information processing; (3) Teaching them in regular and demanding training sessions; (4) Provide advice during the decision-making process. While the goal of the DMT is to provide support in all points this paper focuses on the decision making aspect and discussed how computer based tools can help decision-makers by systematically supporting their decision-making process.

This paper starts with a short overview of the Disaster Management Tool (DMT) in which the elements presented here are embedded. After a description of the architecture the main part of the paper discusses the decision-making process based on the Recognition-primed decision (RPD) model (Klein 1989; 1997) and how the process can be supported and enhanced by a computer system. Concluding, the evaluation of this system during an exercise for earthquake disaster response in Bucharest in Romania is discussed.

SYSTEM COMPONENTS

This decision support system is part of the so called Disaster Management Tool (DMT). It integrates various techniques in a framework to provide support for all phases of disaster management. The test area for the system is a part of the downtown district of Bucharest for which high-resolution data was acquired including detailed information for each single building. As the city has a high risk for major earthquakes the elements of the system are oriented towards this topic but could be used for other disasters as well. The system includes a simulation of the progression of a disaster, e.g. fire propagation and consequences of decisions. A damage and casualty estimation based on seismic data is performed by the component EQSIM (Fiedrich et al., 2002) as well as decision support agents providing advice for the allocation of resources (Fiedrich, 2006). These elements are embedded in an information system providing a GIS supported user interface with a messaging system for EOC members.

Application area of the system

The DMT uses a modular approach within a single disaster management framework where single modules can be reused for different disaster management domains. The following paragraphs give an overview of the systems scope:

- During *planning* the DMT provides detailed disaster scenarios to support the development of disaster response plans and provide risk assessment. This helps defining the needs for personnel and equipment of response teams for a specific scenario. The system also supports collaborative work on a scenario by using different software clients.
- The system also provides a *virtual training* environment for real time exercises for the members of an EOC by replacing missing field personnel by simulated response units. It generates a virtual real time exercise without having the need of a full scale exercise. Simulated resources include SAR-Teams, ambulances, fire fighting units, reconnaissance units and heavy equipment resources for repair works of blocked roads and rescue operations (Fiedrich & Gehbauer, 2004). Furthermore, it is possible to combine the input of real and simulated units giving the participants of a training session an even more realistic impression.
- Besides planning and training the DMT can also be applied during *disaster response*. The DMT includes an expert and information system to support Search and Rescue teams during their operations. This system provides recommendations based on manuals, an expert system and calculation components. Case-relevant checklists can be printed and appropriate tools and methods are recommended. It also provides communication with control personnel and data-exchange.

These parts of the DMT are completed and were already tested during an exercise with the Romanian Civil Defense in 2004 (Markus, 2006).

Decision support components to support the planning process of EOC personnel during the response phase are still under development. Typical functions of EOC members include a huge variety of different responsibilities such as the declaration of a local emergency, dissemination of emergency information to the public, resource tracking, etc. The system presented here is focussed on the topic of resource management with the emphasis on prioritising the allocation of the available resources. The decision support agents responsible for this task are able to autonomously control response resources to simulate the work of EOC members and to generate model solutions for training scenarios. But their main task is to provide decision support in real disaster situations as described later. There are a number of approaches to apply agent technologies to areas relevant to emergency response, including earthquake disaster response (Tadokoro et al. 2000), forest and bush firefighting (Au, 2000; Jaber et al., 2001) and flood management (Molina and Blasco, 2003). So far these approaches are not able to improvise on given situations and they mainly use plan-based reasoning based on predefined plans which depend on constraints resulting from the current emergency situation. The goal of the decision support component in the DMT is not a purely scientific proof of concept. Hence the paper will discuss the current range of realistically applicable computer-based decision support from the authors' view.

THE SYSTEM ARCHITECTURE

The system architecture (Figure 1) is divided into three parts: simulation, decision support and human computer interaction (HCI), all of them accessing one central database. The simulation uses the High Level Architecture (HLA), a special framework for distributed simulation. The core components are realized as agents in a multi-agent system (MAS). Depending on the needs different simulations can run each with its own mediator agent, controlling the simulation and transmitting its results. The whole system is designed to be modular and distributed. Elements can be added and removed arbitrarily and new functionalities can easily be integrated simply by adding a new component.

An XML-based message format is used to exchange information between the agents. The format is oriented on XML communication standards for emergency operations, namely MayDayML in the MESA Project (www.projectmesa.org) and CAP (Common Alerting Protocol) and EDXL (Emergency Data Exchange Language) from the OASIS (www.oasis-open.org) consortium. Messages in this format could easily be converted in a human readable format and the structures of messages can store user input easily. As a result the components are commutable, e.g. the input from the simulation through the *Mediator Agent* could be replaced by real humans on *Field Unit Interface Agents*. The selection of the XML-Format also ensures easy interoperability with non-agent based systems, e.g. the "Field Unit Expert System" in the DMT communicates through a *Message Proxy Agent*.

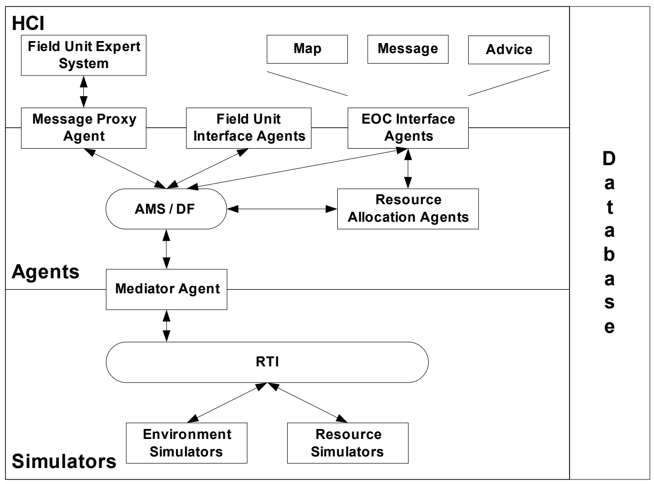

Figure 1. The system architecture of the DMT

The simulation reproduces the dynamic aspects of the disaster world and the response operations of the resources. It is realised by an interaction between resource simulators and environment simulators, e.g. fire fighting is an interaction between the fire simulator and the fire brigade simulator. HLA is an approved platform for distributed simulations and since 2000 an Institute of Electrical and Electronics Engineers standard. For each simulation the Run Time Infrastructure (RTI) provides the central service for the interaction of the simulators. So far the HLA-based simulation has mainly been applied in the military, as it was developed by the Defense Modeling and Simulation Office (DMSO) of the Department of Defense (DoD). Nevertheless, some simulators for comparable fields like logistics (Reyns et al., 1998), emergency medical treatment (Pettitt et al., 1998) or natural environment modelling (Gerrard et al. 1999) have been developed. More recently there have been increasing efforts to apply HLA to civilian domains, such as traffic and logistics (Strassburger, 2001) or emergency management (Klein, 2001).

The core system is comprised of agents connected to a MAS. Its framework follows the FIPA Agent Management Specification (see www.fipa.org), which defines the physical infrastructure for an Agent Platform (AP) in which agents can be deployed and consist. The Agent Management System (AMS) is mandatory for every AP. It has supervisory control over the access and use of the AP and offers white pages services to other agents. Additionally, the Directory Facilitator (DF) provides yellow pages services so agents may register their services with the DF or query the DF to find services offered by other agents. Three types of agents exist:

- *Interface Agents* are responsible for the human-computer interaction and provide the views for the results of the simulation and the advices of the decision support agents. Depending on their task they have different capabilities. While the EOC agents include a geographic information system (GIS), an interface for the decision support and a messaging tool, the agents for field units only consist of the messaging tool for receiving orders and sending reports.
- Each *Mediator Agent* represents a simulation in a multi-agent environment. It translates messages from the agent environment to the HLA simulation and vice versa. The Mediator Agent sends a message from a simulated response resource in the same format as an interface agent of a real world resource would do. Therefore simulated and real resources can be mixed for training applications. A *Proxy Agent* doesn't translate

messages because it receives and sends message in the XML-Format of the DMT. Its only task is to distribute this message to different environments, e.g. the FIPA-ACL environment and E-Mail.

- *Decision Support Agents* are response-related and based on the Belief-Desire-Intension (BDI) concept. The BDI approach was very much influenced by Bratman (Bratman, 1987) and software agents following this paradigm have been applied successfully to different real world problems such as fault diagnosis for the space shuttle or air-traffic management (Ingrand et al., 1992). A BDI-agent pursues its given goals (*desires*), adopting appropriate plans (*intentions*) according to its current set of data (*beliefs*) about the state of the world. The plan library of the agents is based on the analysis of emergency plans and standard operation procedures as well as expert surveys. Currently only decision support agents for EOC members are implemented (see Figure 2). They provide their advices as a kind of service which can be inquired by a human decision maker by the Interface Agents. Also when not interacting with a human the *Decision Support Agents* continuously evaluates the situation in the disaster environment autonomously to keep track of the dynamic changes.

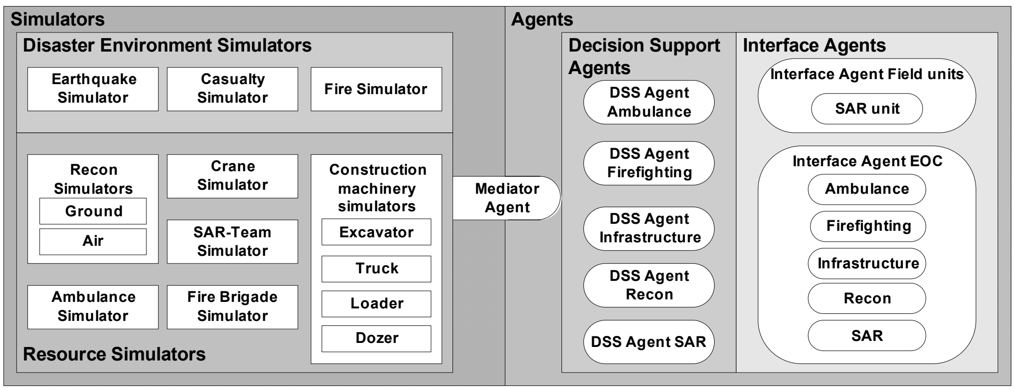

Figure 2. Overview of agents and simulators

The following sections show how these agents and simulators are used to provide decision support for EOC members. For further details about the architecture and agents see Engelmann (2006) as well as Fiedrich (2006) for the simulation components.

DECISION-MAKING OF EOC MEMBERS

Decision-making during disasters is marked by key features like dynamic changing conditions, uncertain and missing data, time pressure and the need for real-time reaction, ill-defined tasks and goals as well as significant consequences for mistakes. As a result the decision-makers face a lot of pressure and have to make decisions based on uncertain information.

Taking a look at different models describing the human decision-making process two opposite modelling approaches can be identified. The first ones are analytical models describing decision-making as an analytical process where the problem and/or different solutions are analysed in detail to find an optimal decision. Examples for this approach are the Multi-Attribute Utility Analysis (MAUA) or the Decision Analysis. The second ones are recognitional strategies in which the decisions are based on the application of experience of the decision-maker to a situation. The Recognition-Primed Decision (RPD) model can be assigned to this type (Klein 1989; 1997).

To choose the right support for the decision-makers in an EOC it has to be determined which model matches their decision-making strategy. As Klein developed the RPD based on the experiences of commanders in the fireground environment it seems that this matches the situation after an earthquake. But as the situation in an EOC does not seem as stressful as in the field, it could be assumed that an analytical process is also possible. What speaks in favour of the use of the RPD model is the stress resulting from the time pressure in which a solution must be found and from the responsibility for many lives. In additional, the decision-makers in an EOC are generally former field commanders and therefore they are used to this decision-making process. Both facts have been approved in interviews with EOC members and personnel of a training facility for disaster management in Germany.

Decision-makers in an EOC are usually domain experts with many years of experience. But the management of an extensive disaster like a major earthquake will be most likely a task that exceeds their abilities. The use of computer systems could be used to provide adequate decision support. To see which specific tasks need to be supported, the following section will describe the RPD model before discussing where computers can assist decision-makers and can help to improve the quality of decisions.

The RPD Model

The RPD model is based on the assumption that domain experts make decisions without performing rather time-consuming analyses. Instead they rely on their ability to recognise and classify a situation. Based on this they are able to find a matching workable and efficient solution in a timely manner. Especially time is an important factor in decision-making after disasters because acting too late may result in an out-of-control situation and a direct impact on the number of victims. So time is a key feature for the design of the decision support system. Figure 3 shows the RPD model (Klein, 1989). It consists of two parts: *recognition* and *evaluation*.

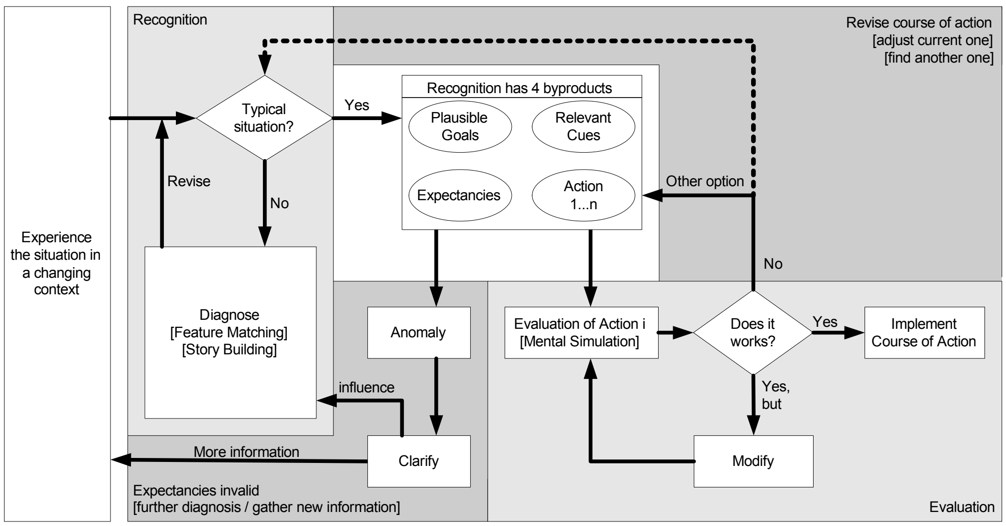

Figure 3. The RPD Model

In the *recognition* phase the decision-maker tries to develop situational awareness and to recognise similar events. If no instant match can be found further diagnosis of the situation is needed. The model states two typical strategies for this, *feature matching* and *story building*. In the feature match the decision-maker tries to match the information describing the current situation with pattern of cues from his experience. If matches found are inadequate, due to lack of experience or a unique situation, story building strategies may help to construct an explanation. The observed cues of the current situation are coherently linked together. This builds sets of hypothetical stories in the mind of the decision-maker which are then compared to the observed events to find the most probable explanation.

The recognition process has four results: (1) *Relevant cues* are identified in the recognition phase and describe what to pay attention to in the recognised situation. (2) Based on the situation there are *plausible goals* which should or could be achieved. (3) A *course of actions* is recognised which will reach the goals. (4) *Expectancies* about what should change in which way and what should happen. The expectancies serve as a way to monitor whether current recognition is still reasonable. Changes in the environment or new information could lead to the result that the current chosen recognition might not match the situation and has to be changed or modified. To *clarify* such an *anomaly* the diagnosis has to be repeated as it is influenced by the changing parameters and the input of new information.

Before the course of action defined by the recognition can be implemented the decision-maker tests it. He mentally simulates the actions and their possible results. If this *evaluation* of the actions shows resolvable problems he modifies them and tests again. In case of a severe mismatch the decision-maker might chose a different course of action based on the current recognition or he examines a new one. The evaluation process only checks for plausibility (“Does it works?”) and not for quality (“How well does it works?”), a point where a computer system may improve this evaluation.

Depending on the complexity of problem steps in the recognition or evaluation are skipped. If the situation is directly recognized and the reaction is obvious, we have a simple match in which the recognition and evaluation are left out and the course of actions is implemented directly. Another possibility is that the decision-maker instantly recognises a nearly similar situation but has to modify his solution slightly. In this case he skips the recognition and develops the course of action by modifying the solution in the evaluation phase.

DECISION SUPPORT BASED ON THE RPD MODEL

Decision support in a EOC

The RPD model was the starting point for several related research approaches. Liang et al. (2001) used neural networks to represent experiences during the feature matching process. There are also attempts to use agent technologies in combination with the RPD model to simulate human behaviour (Sokolowski, 2003) or to provide support for decision making in teams (Yen, 2005). But none of these approaches can replace the human decision maker. Modelling all aspects of decision making for a specific domain creates the need to compile huge knowledge bases. Especially the modelling of the story-building aspect seems to be problematic because as till now a machine cannot match humans in the ability to improvise and adapt to a new situation. Following this, decision support should focus on the decision making principles themselves and not on mimicking specific decisions. This is supported by discussions with decision-makers in which two major problems with computer-based support systems were identified:

1. *Blind trust*: Users accept a system but develop a blind trust in its advice. A simple example is the experience in control centres for fire brigades in Germany. Depending on the keywords extracted from a situation description the system automatically generates a combination of response units based on the standard operating procedures. In most cases these suggestions are accepted without further consideration. This may be appropriate for most situations but may also result in some inefficient decisions because the system does not have access to or does not consider all facts.
2. *Missing acceptance*: Others do not accept computers in general or do not trust in their ability to provide help. Possible causes for this are that they are not used to work with computers or they have experienced ill-designed systems. Apart from this the idea that computer systems may replace humans is often present. Therefore, in order to ensure user acceptance it is important to introduce computer-based support carefully and step by step.

As a conclusion to what is technically feasible and what is reasonable from the practical point of view, it seems clear that the goal for a decision support system in an EOC should not be to provide a solution that the user can implement directly. Instead it seems better to support the users in their own phases of the decision-making process. The RPD model is a guideline for the activities that need to be supported and the sequence in which these activities are connected. As this includes varied tasks, different types of human-computer interaction techniques are chosen ranging from “active advice” to “passive criticizing”.

Decision support based on the RPD model

To decide what should be supported the strengths as well as the weaknesses of computers and humans have to be considered. In general, computers are unbeatable in computing power for well structured problems and they are uninfluenced by feelings. But humans are far better at improvising and adapting to unknown situations by relying more or less on their instinct. The situation in an EOC is predestined for an extensive computer-based support. The system provides information they would need anyway, like (1) a map of the situation and (2) a messaging system. In synergy with this the decision-making process can be enhanced by providing (3) an automatic processing of incoming information and (4) components for active support of the decision making process. While the DMT provides support for the first three points, the paper presents the decision support component. The focus of tasks supported lies on the resource allocation, assuming that this is one of the hardest tasks for EOC members in a disaster. The following section will explain the concept realised, assuming that the phases during the decision making matches the RPD model. Figure 4 gives an overview over the supported measures, with a focus on earthquake response operations.

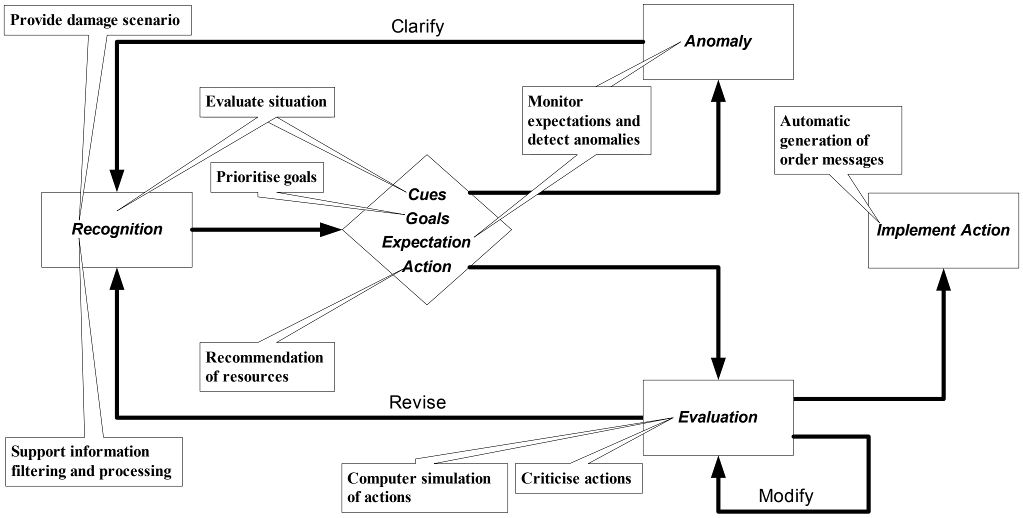

Figure 4. Support for EOC members based on the RPD phases

Recognition

Support during the recognition phase depends on how much time has passed after the initial disaster event. While the first hours are affected by the uncertainty about the situation, the problem later is an overflow of incoming information. To deal with the initial uncertainty a simulation of the disaster is useful. Earthquake parameters available minutes after the earthquake event may be used to calculate initial damage estimates. The EQSIM component of the DMT provides a classification of the expected damages for each single building (Baur et al., 2001). Based on this information the resource allocation planning process can start earlier and the reconnaissance can be optimised.

When the load of incoming information increases filtering and information processing techniques are useful. The DMT provides an electronic messaging system linked with a GIS. It also includes context-sensitive message filtering, for example only showing information for a specific unit or area on the map. The enrichment of a map with information allows a more efficient information access. Combined with the filtering a decision-maker can focus on the information relevant to his currently processed problem. The next step in the development of the messaging system will include a natural language-processing allowing an automatic extraction of information. The evaluation of the situation in an operation area depends on many different given factors as well as the position and the goals of the person analysing them. For the system presented here a diagram used in the crisis management in Germany (shown in Figure 5) is taken as inspiration. It lists sources of dangers and things that could be affected (Knorr, 2000). Realised as an electronic score card it helps the decision-maker to keep track of the current situation and to prioritise operation areas.

First, the person using the scorecard has to configure it to his priorities, which depend on the situation and his domain. The importance of things that could be affected (lines in diagram) is rated on a scale between “less important” and “very important”. For example human life is rated much higher than material assets. After this the real evaluation process starts. The fields in the table have to be filled in for each newly reported operation area. The rating depends on how serious the risk seems to be or whether it is not present or unknown. Some fields can be filled in automatically by predefined scores for special events or calculated if appropriate evaluation methods exist. Examples are the risk for persons inside a damaged building and fire propagation. The risk for persons is evaluated depending on the building damage, its occupation class and the time at which the disaster took place. The fire propagation risk is simulated by the decision support agents. This reduces the number of unknown fields which the decision-maker has to fill in. In addition the scorecard for each operation area is accessible by any member of the EOC and can be modified to achieve a common situational awareness.

Based on this risk assessment the operation areas can be prioritised. Some risk factors have a positive effect on the priority and others have a negative or no affect. The fire propagation and the injury risk for persons are examples for positive factors regarding the priority for fire brigades, while a high risk for an explosion is negative for SAR teams.

The influence of the different risk factors on the priority calculation depends on the domain of the decision-maker. Based on this calculation operation areas are grouped to one of four priority levels. Giving no exact ranking avoids a misplaced certainty in the result and forces the EOC member to make his own evaluation. The boundaries between the priority levels are dynamic, ranging between minimum lower and maximum upper values. Amongst other things the number of operation areas and the available resources are taken into account. Based on this information the decision-maker has to choose the operation area which he rates to be the most urgent.

Means danger for: \ **Sources of danger:**	respiratory toxins	angst behavior	propagation	atomic risks	chemical risks	disease / injury	explosion	collapse	electricity
persons	+	+	+	+	+	+	+	+	+
animals	+	+	+	+	+	+	+	+	+
environment	+		+	+	+		+		
material assets			+	+	+		+	+	+
personnel in the field	+	+	+	+	+	+	+	+	+
equipment			+	+	+		+	+	+

Figure 5. Evaluation of dangerous situations

Recognition products

When choosing an operation area the decision-maker already has an idea what *actions* are needed to resolve the situation, which includes his *goals*. In the case of an EOC he knows which units have to be sent. The relevant *cues* of the recognition are the input of the priority level for the operation area and additional cues of the decision-maker not accounted for in the current computer model. A model for the *expectations* of the decision-maker is a matter of the ongoing research. Based on this expectation model a monitoring for *anomalies* will be implemented.

Concerning the detailed implementation of *actions* the system provides support for the allocation of resources to operation areas. As precise suggestions on actions could lead to an unquestioned adoption the system provides a selection of available resources that seem to match the situation. The decision-maker still has to decide the detailed compilation. In this process sources of risk are accounted for, too. Examples are a fire with respiratory toxins where fire brigades with breathing protection equipment will be recommended or a collapsed reinforced concrete building where SAR teams with special equipment are recommended. The system also tries to select the resources with the shortest and least risky routes to the operation area. But the final decision is still the responsibility of the decision-maker, who may even select units that are not in the proposed list.

Evaluation and Implementation

Before sending a set of units to an operation area the decision-maker evaluates his action. The system tries to support him with criticism on possible mistakes and with the ability to simulate the consequences of an action.

Critique of user actions is another interaction type for decision support systems (Guerlain et al. 1999).The system monitors the chosen units with different methods and comments on possible mistakes. First it checks for rule violations based on the risks identified for the operation area and general situational information. Examples are again breathing protection and special SAR equipment. It is also checked whether the units have access to the operation areas. If a respective simulator is available the decision support agent can use it to check the deployment of the unit for possible problems, e.g. if a blocked road could be cleared with the deployed resources. If the result is inadequate the decision-maker may reconsider.

A decision-maker can also use simulation components to evaluate different courses of action. This computer support for the mental simulation of actions adds a qualitative element to the evaluation phase, as the decision-maker is able to test different strategies for the given situation to find the best matching solution. Based on the result of his simulations and the criticism the decision-maker may implement his course of action directly, modify it or even choose a new one.

After determining the best decision the course of action has to be implemented. As an electronic message system is integrated in the system the decision-maker just has to acknowledge his choice and appropriate messages are automatically sent to the units. The recognition phase starts again with the selection of a new operation area or the processing of new incoming information.

SYSTEM EVALUATION

While the simulation and agent components of the system are already implemented and tested (Fiedrich, 2006; Engelmann et al., 2006) the decision-support component presented in this paper is currently still under development. In late 2007 the system will be tested in a computer-assisted exercise with the Romanian General Inspectorate for Emergency Situations. The exercise scenario will be based on a major earthquake in Bucharest. In addition to simulation generated events a human operator can inject additional events during the exercise (e.g. a train accident). The decision-support component will be integrated in the messaging and GIS computer interface for EOC members and it will provide decision support for the persons responsible for the assignment of fire brigades, ambulances and SAR teams as well as the rebuild of the road infrastructure. Participants will receive three days of training and system introduction.

Communication during the exercise will be directed almost exclusively through the electronic messaging system which stores all messages from the simulation, agents and human actors for later analysis. For documentation purposes the exercise will also be videotaped. Additional personal feedback will be obtained during the debriefing of the participants. The collected data will be used to evaluate the presented decision-support system.

CONCLUSION

This article has presented a practice-oriented approach for the decision support in an EOC focussed on the resource management. The RPD model is used as a model for the decision-making of EOC members and each step in the decision-making process is accompanied by the computer. The presented concept suggests that computer-based support is able to improve the decision-making by adding a qualitative component to the evaluation process in the RPD.

However, the work on this system is far from being completed. The implemented ranking system has to be adjusted with further tests and additional expert judgement. In the future further simulators and decision support agents for new disaster situations like flooding may be integrated into the system.

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