A Design Approach to an Emergency Decision Support System for Mass Evacuation

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ABSTRACT

This paper is directed primarily to investigating the information needs of emergency managers following recognition of a risk of volcanic eruption. These needs include type of information required during the collection, integration, synthesis, presentation, and sharing of information. This will identify and model the processes underpinning the design of an emergency decision support system (EDSS). Exploration of the information needs, flows, and processes involved in emergency decision making can improve the design of EDSS both in terms of their content and the all-important human-system interfaces that determine their usability.The information attributes and flows then lead to the development of a prototype system that can be evaluated to test and refine the concepts.

Keywords

Volcano, EDSS, Ontology, Decision Support System, evacuation, information needs, emergency

INTRODUCTION

In order to cope with big disasters like volcanic eruption, flood, tsunami, hurricane or an earthquake in highly populated city, the optimal provision of information concerning the situation is essential. Emergency managers must identify information relevant to the prevailing situation and relate it to context so that various options can be evaluated to tailor appropriate responses. At the same time information systems being used must also accommodate the ever-changing dynamics of emergency situations by presenting the enhanced true picture of situation.

New Zealand's one third population and 38% of all business enterprises reside in city of Auckland. Volcanoes are a conspicuous feature of Auckland; within a radius of 20 km of central Auckland there are 49 discrete volcanoes. The risk of eruptions is small but it is important to be prepared. Once an eruption is considered imminent, decisions have to be made regarding when to evacuate citizens, the numbers to evacuate, the location to evacuate, and the routes to take etc. Clearly, evacuation causes financial, physical, psychological and social upheaval and the disruption should only be considered when the benefits of leaving are judged to out-weigh significantly the risks of staying. Incorrect and untimely decisions can cost lives and poorly managed evacuations can also lead to a strong resentment of the emergency organizations authorities which can jeopardize their future ability to act effectively. Computer based emergency decision support system (EDSS) that can lead to better emergency decision making (EDM) and the management of disaster response is evidently highly desirable.

The research described in this paper is directed primarily to investigating the information needs of emergency managers following recognition of a risk of volcanic eruption. These needs include determining the type of information required, collection, integration, synthesis, presentation, and sharing of information that identify and

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model the processes underpinning the design of the EDSS. The information attributes and flows then lead to the development of a prototype system that can be evaluated to test and refine the concepts.

MODELING OF EMERGENCY DECISION MAKING

Much of the research on EDSS has focused on support for specific disaster scenarios, e.g. floods (Mirfenderesk, 2009), environmental situations (Hernandez & Serrano, 2001; Liu, 2004), chemical incidents (Yeh & Lo, 2004, transportation (Yoon et al., 2008), or more generically on DSS technologies, e.g. advanced knowledge models for aggregating the knowledge of geographically separate experts (Mendonca et al., 2000), intelligent mobile decision support triage (Padmanabhan et al., 2006), artificial intelligence and EDSS (Cortes et al., 2000). Gunnarsson and Stomberg (2008) have suggested that knowledge and experience of working in different environments are key factors in determining the quality of emergency decision making. Literature review shows that there are comparatively few studies of emergency decision making from a process perspective.

Exploration of the information needs, flows, and processes involved in emergency decision making can improve the design of EDSS both in terms of their content and the all-important human-system interfaces that determine their usability. This exploration, and the subsequent system development, should clearly involve the users (Niculae et al., 2004) to ensure that the EDSS not only supports appropriate decision making but facilitates it by imitating the natural way in which users work. This leads to a new decision making model as a basis for EDSS which discusses many aspects beyond the technical. Key elements in this new model reflect the emphasis on the decision makers and their environment. It includes their knowledge, training, and decision making ability, information on available resources, risk level and stress. The combination and interaction of these elements contribute to the decision makers' *situation awareness* and this concept is proving valuable for a better understanding of emergency decision making and systems design.

SITUATION AWARENESS (SA)

Situation awareness (SA) is an understanding of what is going on around us. Endsley (1988, 2000) defined SA more formally as "the perception of the elements in the environment within a volume of time and space, the comprehension and the projection of their status in the near future". SA therefore has three components (Endsley, 2000).

1. The *perception* of data via the senses, typically though not exclusively, by sight or sound,
2. The *comprehension*, sifting, and elimination of irrelevant data to extract useful information that can be synthesized, integrated, and directed to the user's goals.
3. The *projection* or interpretation of this information to predict its consequences and forecast future situations from the existing and previous situation.

Additionally, the above account emphasizes the importance of previous knowledge and experience as indicated by Gunnarsson and Stomberg (2008). A further point – the SA components are clearly sequential in nature but their execution should be interpreted as an iterative rather than a single-pass process (Endsley, 2000). Thus a projection may highlight the need for further information, which requires data previously considered irrelevant and rejected in stage 1. Additional data acquired as the emergency situation changes may also alter projections.

Endsley's definition of SA and the work of other researchers imply that once users have acquired the relevant awareness they can then direct it towards the achievement of user goals. Our contention is rather that user goals are part of situation awareness since the decisions made in stages 2 and 3 are contingent on a desired outcome which is an objective of the response to the emergency and the recovery process.

The topic of SA is undoubtedly an important one and a fertile area of research for the modeling, design, and implementation of EDSS. The relation between SA and decision making has also been discussed by (Admans et al. 1995). The seminal work of Endsley (1988, 1995) also draws attention to cognitive and information processing theory (Wickens, 1992) from which she has proposed a model for SA based on several key cognitive processes including attention, working memory, long-term memory, mental models, pattern matching, goals, expectations, automation and data/information quality. Consideration of these factors while designing an EDSS will improve situation awareness and so decision making.

We turn now to the application of some of these ideas to a design study we are undertaking for an EDSS that supports mass evacuation following a volcanic eruption; a scenario of (perhaps increasing) relevance to New

Zealand as already indicated. The findings from this work will produce a framework that can be used to design emergency response systems for other scenarios and circumstances.

INFORMATION NEEDS OF EMERGENCY MANAGERS IN MASS EVACUATION

In New Zealand, a major volcanic eruption would involve the fire, medical, and police services along with specialist, organizations such as the government's Institute of Geological and Nuclear Sciences (GNS) and Meteorological Office (MetService). As mentioned above, overall responsibility for emergency management rests with Ministry of Civil Defense Emergency and Management (CDEM), which is highly dependent on the expertise and knowledge of these and other organizations. Initially, technical information from various sources, e.g. GNS, is collected and analyzed to monitor the seismic activity to decide if it is really an indication of volcanic eruption. Depending on the decision further steps are taken. Volcanic activity is closely monitored and information is analyzed for possible vent location and time of eruption. Available seismological, geographical, and statistical knowledge are used to process the incoming information from sensors. If there is reasonable uncertainty regarding the possibility of a full-scale eruption then it may be better to delay a decision to evacuate and avoid the attendant expense and disruption. However, delaying too long will clearly increase the risk and may cost hundreds and possibly thousands of lives. An EDSS that can draw on previous data and experience to aid this decision will be of tremendous value in this situation.

Once an affected area is indicated and the decision to evacuate the population is made, the planning for mass evacuation can begin. The logistical choices then depend on factors such as the location, time of eruption, affected evacuation paths, and most importantly, on the available resources. The difficult judgment arising from these logistical decisions involves predicting the response of the general public to the evacuation decision, which determines the number of people needing assistance and hence the resources needed. Again, an EDSS with information on previous resource needs and current availability can help decision makers in planning the evacuation by showing the outcomes of various possible decisions constrained by resource limitations, concerns about public safety, cost, and other factors. As this study is the first of its kind in the Auckland, some basic questions need to be answered. These include:

- What are the main factors that affect mass evacuation decisions in Auckland volcanic eruptions?
- How do emergency managers develop situation awareness?
- Where and how can EDSS be used to improve situation awareness and decision making?
- Whether the use of EDSS will improve the overall decision making process?

The first stage in answering these questions will involve requirements gathering and information needs analysis using a modified form (see Figure 1) of the Goal Directed Cognitive Task Analysis (GDIA) technique discussed in detail by Prasanna, et al. (2009). This technique is chosen because of its clearly-defined and repeatable steps and its previous application in the emergency services area. The analysis will be based on interviews (10 -12 in the first instance) with emergency managers and decision makers covering key roles such as Evacuation Coordinators, Resource Coordinators, Health Workers, Scientists, etc. Some of the interviewees will have participated in *Exercise Ruaumoko*[1] (2008), an extensive simulation exercise held in 2008 to determine preparedness and improve situation awareness for volcanic events. This initial stage will lead to a decision processes model that will indicate the procedures that can be automated or supported by the EDSS. A prototype EDSS will be built around this model and evaluated using the Ruaumoko eruption scenario (Javed et al., 2009). The design of the prototype, dubbed SAVER (Situation Aware Volcanic Eruption Reasoner), is described below.

[1] In Māori mythology, Ruaumoko is the youngest son of Rangi and Papa, god of volcanoes and seasons.

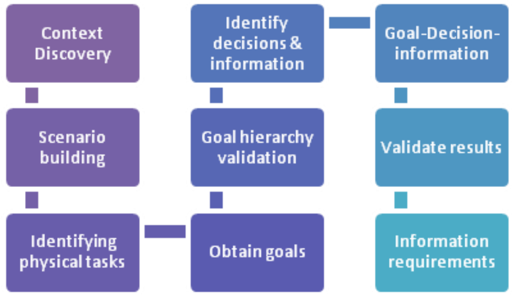

Figure 1. GDIA Technique (adopted from Prasanna, et al., 2009)

SITUATION AWARE VOLCANIC ERUPTION REASONER (SAVER)

SAVER is intended to draw together information from relevant sources to present the required information upfront to a decision maker rapidly and in an accessible format (Endlsey, 1998) together with recommendations for action supported by reasoned explanations. The manager can then evaluate the recommendations. This process provides confidence that key scenario factors have been identified and appropriate solutions considered. The human decision maker can override the system recommendations if he/she feels that SAVER has not addressed all of the relevant issues, although the more likely outcome is that the manager will find that the memory, pattern matching, and goal-orientated features of the system will fill the gaps in user knowledge and enhance situation awareness.

SAVER's operation will employ the three-stage model of situation awareness outlined above. By providing the context to the information on stage 1, SAVER will provide comprehension (stage 2) and projection(stage 3). Examples include predicting information on available resources after say four hours, or forecasting the number of people in need of assistance at a particular time with specific needs like patients etc. Projection can play an important role in planning for emergency response, mass evacuation and overall decision making. The SAVER technology will 'save' all of the system output and interaction with the user not only to provide an audit trail charting the response to the volcanic event but to provide the material to update the knowledge base.

Another research theme to be investigated is the role of ontological structures within the SAVER architecture (Guarino, 1998). Domain ontology is a description of a specific domain that contains descriptions of the classes (concepts) and objects in that domain, and the attributes, features, and properties that can depict relationships between the classes or objects. These relationships then generate logical rules and restrictions that can be used to derive inferences from assertions. In SAVER, ontology-based reasoning will be studied as a proposed solution for improving situation awareness. The idea is to see if the attributes of a situation can be specified as concepts of domain ontology together with governing rules and relations so that future values of the concepts can be derived. The approach would parallel Endsley's model as shown in Figure2.

Figure 2. Ontology-based situation awareness

EVALUATION

Evaluation of the entire emergency response system is essential to validate its suitability for dealing with emergencies. Emergency managers from key organizations will participate as decision makers in a set of simulations adopted from Ruaumoko emergency exercise scenarios mentioned earlier. The participants will respond to various situations with and without SAVER. The simulations will be compared using measurable parameters (Endsley, 2000; Strauss & Kirlik, 2006) such as emergency recognition and processing times, and the numbers of „correct" decisions. The second simulation will also be designed to evaluate each component of SAVER for consistency, usability, and robustness apart from the basic information needs of emergency managers. As well as offering a useful index for evaluating system design and performance, the direct measurement of situation awareness provides insight into how decision makers piece together the array of disparate and dynamic information to form a coherent operational picture (Endsley, 2000). The tests can also help to determine the degree to which new technologies or design concepts actually improve or degrade the decision making.

CONCLUSIONS

This paper has discussed a design approach towards the development of EDSS that can be used to improve decision making after the recognition of a volcanic eruption scenario. The design is based on Endsley's model of situation awareness which identifies perception, comprehension, and projection as stages in decision making. The approach will use cognitive task analysis and ontological structuring to model these stages and identify the information needs and processes involved. Following the evaluation of a prototype, the study will yield a framework that can be used to design and implement an emergency decision support system that will optimize decisions and help to employ resources both efficiently and effectively. The framework will also be applicable to other disaster scenarios.

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