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**Design and Evaluation of Mass Evacuation Support Systems  
Using Ontologies for improved Situation Awareness**

A dissertation presented in partial fulfilment of the requirements for the degree

of

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in  
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# Abstract

Large-scale emergencies, such as tsunamis, are managed by several teams, e.g. emergency managers, military, police, fire services, health care professionals, etc. Close co-ordination within and between teams is essential since the failure of a single link can risk the whole operation, for example, the mass evacuation of a city or region. Decision-making in such emergencies is necessarily complex as the situations are dynamic, unfolding rapidly, and invariably stressful. Computerised decision support systems can facilitate and improve co-ordination and decision making by presenting, structuring, processing, and interpreting huge amounts of information in a short span of time.

However, the power of such systems is enhanced even further if they are designed to improve the situation awareness (SA) of individual managers, their shared situation awareness (SSA), and team situation awareness (TSA). The goal is to ensure that team members have a comprehensive understanding of the situation, not just for their individual roles but also for the roles of their colleagues. The aim of the thesis is to design a computer based information system to support SA, SSA, and TSA of emergency managers for effective decision making and collaborative task performance. The thesis describes elicitation of the information requirements for various emergency management roles during a mass evacuation using a cognitive task analysis technique. Based on the requirements, it explains the design and development of a computer based system dubbed Situation Aware Vigilant Emergency Reasoner (SAVER) using ontologies for situation assessment and reasoning.

It is demonstrated that ontologies can be used to classify the SA information since they can model the situations in detail and allow the inference on rules and axioms. Ontology based reasoning successfully provided the automatic situation assessment according to the SA levels. The thesis also details the evaluation of SAVER by measuring SA, SSA and TSA of emergency managers using Situation Awareness Global Assessment Technique (SAGAT) in simulated mass evacuation scenarios. The evaluation demonstrated the superior performance of the computer based system for improving SA, SSA and TSA of emergency managers. Moreover, the user interfaces of SAVER were also evaluated positive for the human computer interaction (HCI) parameters such as usability, ease of use, understandability, learnability, functionality, etc.

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- Javed, Y., Norris, A. C., & Johnston, D. M. (2012). Improving Situation Awareness for Mass Evacuation Decision Making Prototype SAVER (Under review). *InderScience: Special Issue in An Interdisciplinary Approach to Crisis Response and Management*.
- Javed, Y., & Norris, A. C. (2012). *Design, Implementation and Evaluation of an Emergency Management System to enhance Situation Awareness*. General Sir John Kotewala Defence University Annual Symposium 2012, Ratmalana, Srilanka.
- Javed, Y., Norris, A. C., & Johnston, D. M. (2012). *Evaluating SAVER: Measuring Shared and Team Situation Awareness of Emergency decision makers*. In Proceedings of 9<sup>th</sup> International Conference on Information Systems for Crisis Response and Management (ISCRAM 2012), Vancouver, Canada, pp. 1-11.
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- Javed, Y., Norris, A. C., & Johnston, D. M. (2011). *Combining Naturalistic and Rational Decision Models for Designing Mass Evacuation Support System (MESS)*. In Proceedings of Intellect International Consortium Academic Conference, 2011. Sydney, Australia.
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- Javed. Y, Norris. A. C., & Stockdale. R. (2008). *Key IT-based Capabilities for Disaster Management and Problems in implementing related promising technologies(Short paper & poster)*. In Proceedings of 2nd Australasian Disaster Management Conference 2008. Wellington , New Zealand.

# Chapter 1

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## INTRODUCTION

*“The best way to predict the future is to invent it”  
(Alan Curtis Kay)*

### 1.1 Aim of the Research

This research investigates the decision making process of emergency managers in various Group Emergency Operations Centres (GEOCs) of New Zealand. GEOC has to integrate information from multiple local Emergency Operation Centres (EOCs) and many other organisations such as the Fire Service, Police, Welfare organisations etc. to develop a team situation awareness (TSA), which is required for decision making. GEOCs also have to co-ordinate the implementation of decisions in the form of actions and tasks by various emergency management teams that require a shared situation awareness (SSA). This research examines how emergency managers develop their individual, shared and team Situation Awareness (SA) in GEOCs.

Many emergency response failures are due to the inappropriate or delayed understanding of the emergency situation at an individual or team level. Examples include deaths during the Indian Ocean tsunami in 2005 due to the late or no evacuation decision, casualties in the Japan tsunami in 2011 due to the delayed evacuation decision, three mile nuclear incident (Janex, 2007), fire fighters death in 9/11 (Son et al., 2009), the mass casualty during the Bhopal incident (Endsley, 1999). In all of these cases, decision makers failed to comprehend the actual situation or to implement the decisions in time.

Much of the available research has been done on an individual's SA and how it can be supported and measured but far less has been published on SSA and TSA, which are more important for large events in which teams of people are involved in decision making and implementation. Individuals from different backgrounds, cultures, experiences and, most importantly, with different goals in mind see situations differently. However, it is very important to reach an accurate and common understanding of the situation as rapidly as possible so that correct decisions can be

made quickly. Similarly, hundreds of different organisations may be involved in the implementation of decisions in the form of actions, co-ordination between the individual members, teams and their activities; it is vital to reduce avoidable repetition, particularly as the situation may be fluid and changing frequently. Emergency situations can clearly become very complex.

The study described in this thesis draws upon the experiences derived from simulated exercises, namely Ruaumoko<sup>1</sup> and Tangaroa<sup>2</sup>. Moreover, expert opinions obtained by interviews and questionnaires are used to understand the information requirements and flows required for SA development and decision making. This knowledge is then used to design a decision support system dubbed Situation Aware Vigilant Emergency Reasoner (SAVER) to support SA, SSA, and TSA of emergency managers to improve overall decision making during large-scale emergency events. A series of simulated experiments were performed to validate the findings and evaluate whether SAVER can really improve SA, SSA and TSA or not by measuring the SA, SSA and TSA of the participants.

The following section describes the research contribution of this study, and the next section contains an overview of the emergency management research. The subsequent sections describe the research context, problem, objectives, and the scope of the inquiry and finally, an overview of the whole thesis.

## **1.2 Research Contributions**

1. The identification of information required for developing SA, SSA, and TSA during mass evacuation operations using a cognitive tasks analysis technique
2. The recognition of the need of SSA and TSA during mass evacuation operations

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<sup>1</sup> Ruaumoko is the name of the Maori mythological God who is guardian of earthquakes and volcanoes. The aim of Exercise Ruaumoko was to "test New Zealand's all-of-nation arrangements for responding to a major disaster resulting from an impending volcanic eruption in Auckland."

<sup>2</sup> The name for the exercise comes from Maori mythology where 'Tangaroa' is the God of the sea, rivers, lakes and all that live within them. Exercise Tangaroa was a national, multi-agency exercise that was held on 20 October, 2010. The exercise was led by the Ministry of Civil Defence & Emergency Management and was supported by the 16 CDEM Groups, central government departments, emergency services, lifeline utilities, and other agencies as appropriate.

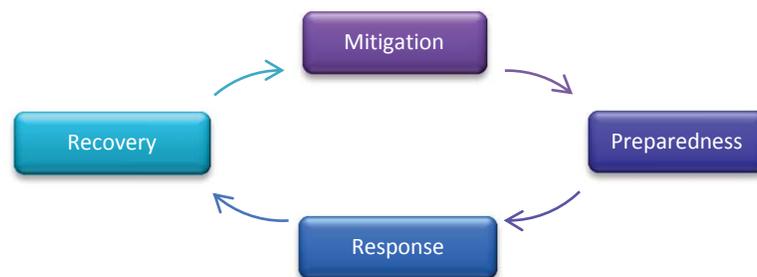
3. The classification of the information requirements according to the mass evacuation operation phases and the emergency management roles
4. The use of ontologies for information classification according to the SA requirements and the SA levels in the computer based system
5. The development of ontologies for the information requirements of SA, SSA and TSA, the emergency management roles, and the emergency situation involving a mass evacuation
6. The design of ontology based context architecture for personalised information sharing to reduce the information overload
7. The design and development of the computer based system prototype (SAVER) for improving individual, shared and team SA of emergency managers
8. The design and development of a computer based system (SAVER) improving the TSA of emergency managers according to all three prevalent models of TSA
9. The evaluation of SAVER using SAGAT technique proving that use of SA oriented system design can improve individual SA using the computer based system
10. The extension of SAGAT for measuring SSA and TSA of emergency managers
11. The evaluation of SAVER using three different TSA models
12. The formalisation of SA, SSA and TSA definitions
13. The division of SSA and TSA into three levels for detailed modelling
14. The discovery of relationships between three different models of TSA

## **1.3 Theoretical Framework**

### **1.3.1 Emergency Management overview**

With the recent increase in serious disasters worldwide, the importance of improving emergency management practices has greatly increased. According to the Merriam Webster dictionary, an emergency is *an unforeseen combination of circumstances or the resulting state that calls for immediate action* (Merriam-Webster, 2011). Common examples are floods, earthquakes, tsunamis, volcanic eruptions, hurricanes, tornados, or acts of terrorism etc. that can bring damage or loss. Nowadays, disasters are seen as the result of inappropriately managed risk, which is the product of hazards and vulnerability. Hazards in the areas with low vulnerability are not considered as disaster, as is the case in unoccupied regions (Quarantelli, 1998).

*Emergency management* is an inter-disciplinary field dealing with the strategic organisational processes used to shield critical assets (living or non-living like infrastructure or economy) from hazards that can cause disasters or catastrophes, and to ensure the continuance of the organisation within their planned lifetime (Haddow, et al., 2007). Emergency management is divided into four phases namely Mitigation, Preparedness, Response and Recovery (Quarantelli, 1998) as shown in Figure 1 below. Mitigation deals with the steps taken to reduce the risk and to prevent hazards from evolving into disaster or to minimize the impact of disaster. Mitigation actions can be structural or non-structural. Structural actions use technological solutions like flood levees, earthquake resistant buildings and bridge structures etc. Non-structural measures include legislation, land-use planning, insurance etc. (Wilson, 2009). Preparedness is a cycle of planning, organising, training, equipping, exercising, evaluation, and improvement activities to ensure the effective co-ordination and the enhancement of capabilities to prevent and respond to the effects of natural and man-made disasters (FEMA, 2007). In the preparedness phase, plans of the actions are developed to manage and counter the risks and take actions to build the necessary capabilities needed to implement such plans. The Response phase includes the mobilisation of the core emergency services and first responders such as fire fighters, police, and ambulance crews etc. in the disaster area. Though this phase requires different actions depending upon the type of disaster, large events such as a tsunami or volcanic risk require the evacuation of people before the incident, as well as rescue and relief during or after the event (FEMA, 2007). The recovery phase starts after the immediate threat to human life has ended. During this phase, actions are taken to bring the community back to normal. Recovery activities continue until all systems return to the normal or better. Recovery activities include returning vital life-support systems to minimum operating standards, e.g. temporary housing, grants, medical care etc.



**Figure 1.1 Emergency management cycle**

Although decisions are made during every phase of emergency management, decision-making becomes especially important during the response phase. In the case of crises like a tsunami or volcanic eruptions, decisions have to be made about the confirmation of the threat, possible area under threat, time of occurrence, areas to evacuate, evacuation start time etc. During decision making, multiple emergency managers from various organisations interact with each other and with the domain experts to understand the situation before making a decision and carrying out their response tasks. Incoming information from various sources is usually general and not necessarily intended or sufficient for a specific decision, role, or task. Consequently, information is processed and understood using an individual's perception which can widely vary according to their background, culture, experiences, stress level or attention level at that time. Hence, the individual's understanding, which feeds into the collective understanding of the team involved in the decision-making, may not be accurate.

### **1.3.2 Decision Making in Emergency Management**

Emergency decision or ordinary decision making consists of two parts: first, understanding the situation by processing the situational information cues and second, suggesting actions to normalise the situation or to make it safe. Incoming information is input to the whole process. Decision making during an emergency situation is different from ordinary decision making in many ways e.g.

- Stress level is very high as lives and structures are at stake
- Limited time is available to make decisions
- The situation is continuously changing
- Incoming information is uncertain and can quickly become out of date
- Information can be either incomplete, or in some cases excessive, leading to overload and the need to extract relevant from general information

These factors affect the information processing by individuals and teams as they try to understand the situation. As information from multiple sources and domains has to be integrated into a meaningful and usable format it becomes very time consuming to classify it according to the requirements of different people who have different roles and goals.

Though disasters like tsunamis cannot be prevented, their impact on society can be minimised by good decision making and by making use of the disciplines such as engineering, management, policy making and community support, which are all related to emergency management. According to Hough (2008), in the last decade more than one million people have died and multibillion-dollar losses incurred due to the direct impact of natural disasters like tsunamis, floods and earthquakes – this figure does not include casualties from the recent Japan earthquake and tsunami of 2011. During the 2005 Indian and 2011 Japan tsunamis, ineffective use of the incoming information needed for timely evacuation led to mass destruction and casualties. Hence, right and timely decision making is the most important part of emergency management as it defines the actions required to normalise the situation or arrange safe evacuation if required. Information technology (IT) is playing a major role in providing support to decision makers in the form of decision support and emergency management systems. However, most of these systems are general purpose systems and the information provided by them needs further processing before use, which adds to decision delays.

### **1.3.3 Importance of SA/TSA and SSA in Decision Making**

The process of understanding the prevailing situation is called situation assessment, this process results in a product named situation awareness (SA). SA is the degree to which a person understands the situation. Several studies have described SA as a crucial factor for better decision making (Bryant, 2002; Klein, 2000) and the seminal work by Endsley and others has shown its close relationship with emergency decision making during time critical and complex situations (Adam et al., 1995; Endsley, 1995a; Smith & Hancock, 1995). As indicated, the exchange of individual Situation Awareness (SA) between managers leads to team situation awareness (TSA) and more accurate and rapid decision making. The sooner team members understand the full picture of a situation, the sooner they can develop consensus and suggest actions to normalise it. Once a decision is made, it has to be implemented by emergency managers/officials from multiple organizations in a co-ordinated way. For this, they have to know about their own responsibilities in the overall operation and their role in relation to others' activities. This understanding is called shared situation awareness (SSA). Hence, TSA is important for the team decision making, whereas SSA is important to the implementation of the decision or to any collaborative task discharged in a co-ordinated way. In the absence of SSA, every team member would be concentrating on only his/her part, ignoring his or

her role in the team. This not only results in the repetition of various activities but it can also delay or curtail tasks leading potentially to the failure of the whole mission due to the inability of team members to integrate their individual and shared awareness.

Some recent research to improve SA in emergency decision making has made use of computer based systems, e.g. (Bergstrand & Landgren, 2009; Betts et al., 2005; Lanfranchi & Ireson, 2009; Prasanna et al., 2009). Several studies (O'Connor et al., 2008; Endsley & Robertson, 2000; Endsley & Rodgers, 1994; Resnick, 2003; Riley et al., 2006) have also explained how a system fulfilling SA requirements can maintain the required level of SA and better support such decision making. However, the studies noted above underestimate the critical SSA and TSA factors. At the same time, very little work has been done to see how SA, SSA or TSA can be developed for decision making and implementation during mass evacuation in case of a tsunami risk.

Another important issue related to the design of computer systems supporting SA, SSA and TSA is the gathering of information requirements. The identification of information required to develop and maintain necessary degrees of SA, SSA and TSA is a challenge since, apart from physical tasks, many cognitive processes are also involved in situation assessment. Therefore, innovative techniques are required to gather the information requirements of physical tasks as well as cognitive processes of emergency managers during team decision making and collaboration.

This thesis aims at understanding the SA, SSA, and TSA requirements of emergency managers for decision making and collaboration during mass evacuation operations. Moreover, based on the requirements, it describes the design, development, and evaluation of a prototype computer system (SAVER) to improve SA, SSA and TSA.

#### **1.3.4 Ontology based SA**

Ontology originated from the area of philosophy (Gruber, 1993). In philosophy, ontology is the science of being or existence. In Information Technology (IT) and Computer Science, however, ontologies are used to define relationships between various concepts to conceptualise the domain or area. More specifically, ontologies can be used as a language for describing content and its structure and the properties and relationships between concepts in a structural and consistent manner. Ontology is defined as a formal, explicit specification of a shared conceptualisation (Studer et al., 1998). The “conceptualisation” refers to an abstract model of some phenomenon in the

world by identifying the relevant concepts of that phenomenon. The “explicit” means that the type of concepts used, and the constraints on their user are explicitly defined. The term ‘Formal’ refers to the fact that the ontology should be in a standard language, which is machine-readable. ‘Shared’ reflects the notion that ontology captures a consensus, that is, not the private idea of some individual, but the accepted and shared understanding of a group.

Ontologies describe objects using individuals (instances), classes (concepts), attributes, and relationships (properties). Classes are the sets of objects (individuals) that share the same characteristics. Individuals include real objects, for example, humans, animals, cars, etc. Attributes are the characteristics of classes and relationships are the associations between classes. From the above explanation, it can be seen that an ontology can be used to model situation concepts, a procedure necessary for computer analysis of a situation. At the same time, the ontology should represent the shared understanding of the concepts leading to the shared understanding of a situation by a group of people with different backgrounds, roles and objectives. An ontological description can therefore facilitate TSA. Another important aspect of ontology use is its specification in a computer-readable language making ontology ideal for computer based situation analysis. Several studies (Boury-Brisset, 2003; Horney et al., 2003; Mathues et al., 2003; McGuinness et al., 2003) have proposed ontology based SA systems. They also provide higher level situation ontologies to capture generic situation descriptions that can be contextualized to derive more domain specific ontologies.

The approach described here in this thesis, endeavours to extend the existing SA ontology for SSA and TSA by modelling contextual and situational information. In situations like volcanic eruptions, floods, tsunamis etc., when expert opinion is required to decide, for example, when to evacuate, which area to evacuate first etc., it is often difficult for emergency managers to quickly integrate information from diverse sources and make sense of it. Moreover, as multiple organisations are involved at different levels of decision making and collaborative tasks, it is impractical to memorise the information requirements of all fellow team members or members from other organisations who depend on them and vice versa. In these circumstances, the necessary levels of SSA and TSA are not achieved. Ontology can be used to model the situation and context in a detail to allow automatic integration of information from diverse sources, provide semantics to the situational objects and most importantly, allows inference and

reasoning capabilities necessary to develop judgements about the understanding of a situation. In this way, they can see how the current situation affects their objectives in relation to other members of the team. This reduces the chances of misunderstanding and the emergency managers can fully understand the dynamics of the evolving situation and its implications. Hence, this study also investigates the possible application of ontologies in the computer based system supporting SA, SSA and TSA.

## 1.4 Research Context

In New Zealand, the National Crisis Management Centre (NCMC) looks after a crisis at national level and co-ordinates with the regional emergency offices known as Group Emergency Operation Centres (GEOCs). GEOCs in turn, co-ordinate with local Emergency Operation Centres (LEOCs), within that region. Co-ordination between NCMC and GEOCs and LEOCs is critical for SA and decision making as most of the major decisions are made by NCMC and implemented by LEOCs and supporting organisations such as the Fire Service, Police etc.

A system known as the Co-ordinated Incident Management System (CIMS<sup>3</sup>) is used for managing the response to an incident involving multiple responding agencies. CIMS has five basic functions: Controller, Planning & Intelligence (P&I), Operations, Logistics and Welfare. All these functions have their own responsibilities during various phases of an emergency situation and need to share situation and co-ordination information. Hence, they are dependent on each other for decision making and collaborative tasks. This research aims at identifying and supporting the requirements of SA, SSA and TSA needed for the effective decision making and collaboration.

To explain the approach, we consider a tsunami scenario. New Zealand has a coastline of 15,134 km and resides in the South-West Pacific Ocean, which is the world's most dangerous area for highly destructive tsunamis. First, individual/team members use seismic and related data to register an underwater event (e.g. earthquake or volcanic explosion) that could cause a tsunami. Deep-Ocean Assessment and Reporting Tsunami (DART) data are then analysed to confirm whether a tsunami has been generated or not. Once tsunami generation is confirmed, areas of possible devastation are marked

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<sup>3</sup>[http://en.wikipedia.org/wiki/Coordinated\\_Incident\\_Management\\_System](http://en.wikipedia.org/wiki/Coordinated_Incident_Management_System)

and planning for possible evacuation is started. Although the priority zones are designated, decision makers must remain aware of other at risk areas. Similarly, decisions to evacuate, and the time and extent of evacuation, should take into account schools, hospitals, and other buildings that may need special attention.

Planning for the safe evacuation of people includes transport, food and shelter, and medical facilities are critical considerations since wrong decisions can lead to either unnecessary disruption or increased casualties and economic loss. The safe return of evacuees, once water levels have returned to normal, is also a major factor dependent on damage, access and services. While evacuees are away from their properties, proper security arrangements are also important. These planning steps have many considerations for individual and team situation awareness. The present research is undertaken to identify and support the requirements of SA, SSA and TSA of the various emergency management roles to improve their decision making and task collaboration during the tsunami threat.

### **1.5 Research Objectives and Questions**

As this research is the first of its kind in this domain and geographical area, some very fundamental questions need to be answered. The main research objective is to find a way to improve SA, SSA and TSA using a computer based system. The following research questions are framed to achieve this objective.

- 1 How to design a computer based system for automatic situation assessment?
- 2 How to design a computer based system supporting human SA in mass evacuation operations?
- 3 How to design a computer based system supporting shared and team SA (SSA and TSA) of emergency managers in mass evacuation operations?

### **1.6 Research Approach**

Design Science Research Methodology is used to answer the questions mentioned above. Design Science (DS) is a problem solving paradigm whose goal is to produce an artefact by using the analysis, design, implementation and evaluation of the artefact. Working with the technology, going through the design and development of the artefact and understanding the issues with the usage of artefact is at the core of this research paradigm. The knowledge generated by this research informs us how an artefact can be improved and how it is better than the existing solutions.

DSR in information systems provides a solution to what are considered to be the “wicked problems” (Brooks 1987; Rittel & Webber 1984). Cases with such problems have the following characteristics:

- Ill-defined environments where user requirements are unclear and unstable
- Complex problems with many intermingling sub-problems
- Design processes flexible to changes
- Effective solution depends upon human cognitive abilities e.g. intelligence or creativity
- Effective solution depends upon human social abilities (e.g., teamwork)

All of the above problems are evident in the design of information systems to be used for decision making and planning in emergencies. Therefore, this study uses Design Science Research Methodology proposed by Peffers et al. (2008). Peffers et al. provide a commonly accepted framework for carrying out successful design science research in information systems and avoids more ad hoc approaches. In addition, to capture the comprehensive information requirements of cognitive processes along with the physical tasks, a cognitive task analysis technique called Goal Directed Information Analysis (GDIA) (Prasanna et al., 2009) is used. The evaluation of the design and prototype (artefact) is done by measuring the SA, SSA and TSA of emergency managers using Situation Awareness Global Assessment Technique (SAGAT) (Endsley, 1995b) in simulation experiments.

## **1.7 Scope of the Research Enquiry**

It is very important to clearly identify and describe the scope of the study. The scope of this study is described as follows:

- In this study, research explorations are limited to only Group Emergency Operation Centres (GEOCs) instead of all the organisations involved as it is very difficult for an in-depth study in the due period.
- Field observations are confined to the national level exercises and simulations i.e., Ruaumoko and Tangaroa or any other evaluation experiments done using similar scenarios.
- The research is focused on emergency decision making during mass evacuation in case of tsunami risk.

- Investigation is carried out only for the most important roles of GEOC, which are Controller, Planning and Intelligence, Operations, Logistics, and Welfare functions who work as team members.
- This research is focused on the management and co-ordination required for decision making and implementation instead of the scientific and technical details of tsunami scenarios. Thus, this research will not provide the scientific interpretation of sensor data etc. All the data values used will be simulated but realistic.
- The prototype is developed for specific simulated scenarios and as a proof of concept to evaluate the model and validate the findings.
- The interfaces are not developed to fulfil the information requirements of all the roles; only those interfaces are developed which are needed in evaluation for the proof of concept.

## **1.8 Overview of Thesis**

This section describes the overall organisation of the thesis and explains the chapter construction.

### **1.8.1 Chapter 2: Theoretical Foundation and Literature Review**

The aim of this chapter is to develop a theoretical foundation of the study and highlight the gap in literature related to the use of information systems for improving SA, SSA and TSA in emergency decision making and implementation. The structure of this chapter is:

- Emergency management and emergency decision making
- Theoretical underpinning of SA, SSA and TSA
- Information systems to improve SA
- Ontology based SA
- Existing ontology based systems

The chapter identifies the significant gap in the literature concerning the use of information systems to support SSA, and TSA in decision making and implementation during emergencies involving mass evacuation. Another gap found in the literature is about the information requirements of SA, SSA and TSA, for various emergency management roles.

### **1.8.2 Chapter 3: Research Methodology**

The aim of this chapter is to provide an overall design of the research methodology used to achieve the research objectives. The main aspects are as follows:

- The overall design research architecture and theoretical foundations for its suitability to this study
- The use of a modified form of Goal Directed Information Analysis (GDIA) (Prasanna et al., 2009) to obtain the information needs of various emergency management roles
- The design and development of the prototype system for improving SA, SSA and TSA
- The use of ontologies in prototype development for automatic situation assessment
- The Evaluation of the prototype to evaluate the model and validate the findings
- The division of the forthcoming chapters according to three inter-linked problems

The main outcome of this chapter is the overview of the design research methodology and clear direction for research activities to achieve the research objectives of the study. Other outcomes are the steps for design, implementation and evaluation of a prototype that can support SA, SSA and TSA. Moreover, the main research problem is divided into three sub problems and is tackled in three separate chapters i.e. 4, 5 and 6 discussed below.

### **1.8.3 Chapter 4: SAVER: Situation Aware Vigilant Emergency Reasoner**

This chapter discusses the problem of gathering requirements needed to develop situation awareness (SA) and the design of a system that can model situations and provide inference to classify incoming information into information required to develop three levels of SA. The chapter then suggests a solution to the problems followed by the design and development of a prototype. In the next section, this chapter describes the evaluation of the prototype designed and developed. The last section discusses the conclusions. The chapter is structured as follows:

- The problem identification
- The suggested solution to the problem

- The design and development started with information requirements gathering.
- The selection of scenarios used in national exercises
- The description of interview processes and observations during the exercises
- Data validation via questionnaire from GEOCs all over New Zealand
- Prototype development
- Testing of the prototype
- Conclusions

The chapter outcomes are the process of SA development and the information requirements of SA. Other outcomes include a prototype designed and developed using ontologies for situation modelling and the testing results of the prototype evaluation. The prototype uses ontology based inference to classify situation information according to the SA requirements.

#### **1.8.4 Chapter 5: Improving Individual Situation Awareness Using SAVER**

The aim of this chapter is to describe the problems of developing accurate situation awareness (SA) necessary for decision making and carrying out collaborative tasks. Moreover, in the next section, personalised and contextualised information is suggested as a solution. Following the suggestion section, design and development of the prototype is conversed in detail. This section proposes ontology based contextual SA information to provide personalised information. The chapter then provides the details of simulated experiments conducted to measure the SA of emergency managers to evaluate the prototype design. This chapter is structured as:

- The problems related to individual SA
- The suggested solution
- The design and development of the contextual SA component of the prototype
- The development of various ontologies
- The description of features of prototype interfaces to improve SA
- The evaluation of the prototype by emergency managers in experiments using SA measurement techniques

Outcomes include the architecture design of a contextual SA information broker, developed ontologies and a prototype system with SA oriented user interface design for enhanced SA evaluation results of the prototype.

### **1.8.5 Chapter 6: Improving Shared and Team Situation Awareness Using SAVER**

Chapter 6 starts with the description of the problem relating to shared and team situation awareness (SSA & TSA). It describes the requirement of developing and maintaining the accurate SSA and TSA necessary for team decision making and collaborative tasks. In the next section, a solution to the problem is suggested. Afterwards, the design and development of a prototype to support SSA and TSA is described. This section also explains the role of ontologies in the development of a system supporting SSA and TSA. In the next section the prototype is evaluated by measuring SSA and TSA of emergency managers in experiments and the results are reported. Conclusion is the last section of this chapter. This chapter is structured as:

- The problems related to SSA and TSA
- The solution suggested to the problem
- The design and development of the prototype component to support SSA and TSA
- The use of ontologies in the prototype development
- The description of the prototype features to improve SSA and TSA of emergency managers
- The results of the prototype evaluation in experiments

Outcomes of this chapter include the architecture design of an ontology based SSA and TSA information broker, ontologies developed to support SSA and TSA, a prototype system, evaluation results of a prototype for supporting SSA and TSA.

### **1.8.6 Chapter 7: Discussion**

Chapter 7 provides the formalisation of SA, SSA and TSA definition on the basis of results. In addition, it discusses the implications of the results in relation to the existing theories and the limitations of the study. The chapter also elaborates on the possible relationship between different models of TSA and their relation with the individual SA. In the next section of the chapter, implementation requirements of operational SAVER are discussed. At the end of the chapter, a summary of the whole study is provided.

### **1.8.7 Chapter 8: Summary, Conclusions and Future Work**

The final chapter outlines the conclusions in the form of answers to the research questions and points to their details in the thesis. Moreover, in the next and last section

of the chapter, possible avenues of future research related to the study are discussed. See Figure 1.2 below for the overall flow of the thesis.

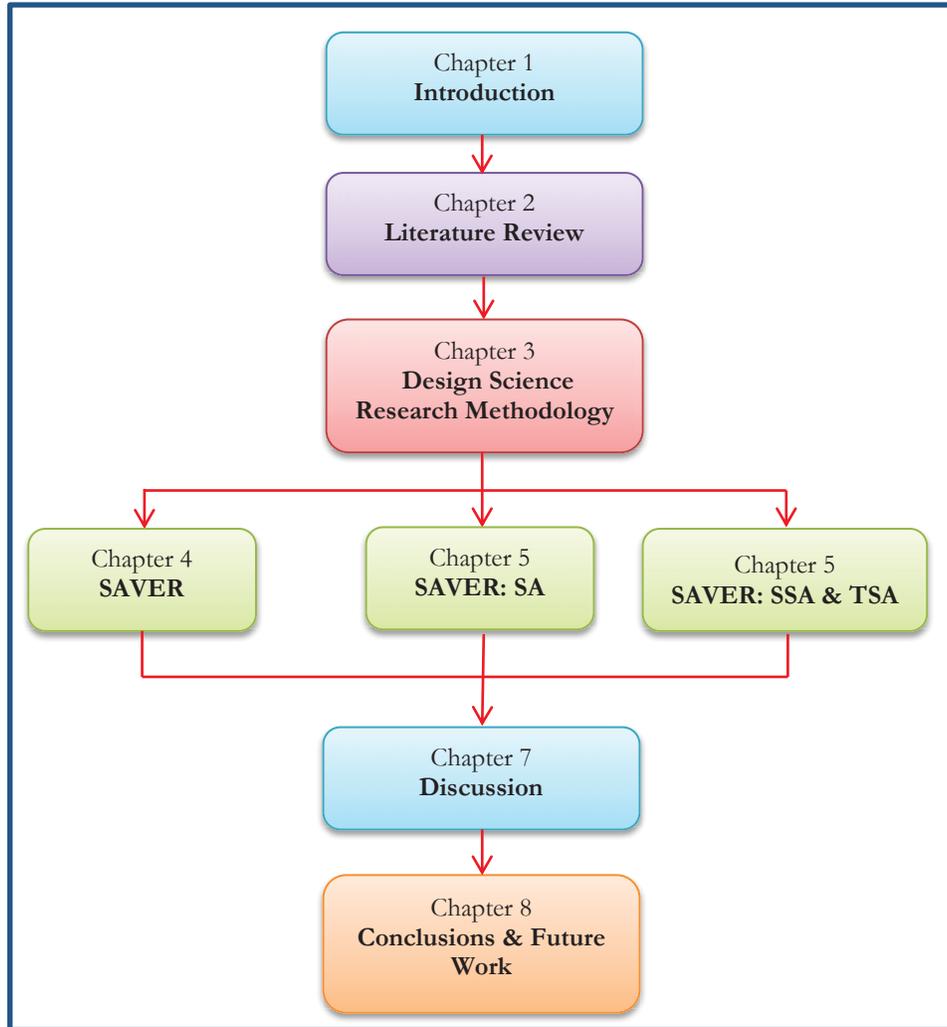


Figure 1.2 Flow of thesis chapters

# Chapter 2

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## THEORETICAL FOUNDATION AND LITERATURE REVIEW

### 2.1 Introduction

The significant increase in the intensity and frequency of natural disasters such as tsunamis, earthquakes, floods and hurricanes has led to an increase in the number of computer systems supporting the co-ordination, situation awareness and overall decision making of emergency managers. Some recent events such as the 2004 Indian Ocean tsunami, when more than 288,000 people died in a dozen countries (Said, Ahmadun, Mahmud, & Abas, 2011), Hurricane Katrina, responsible for 1836 casualties (Knnab, Rhome, & Brown, 2011), and the September 2009 American Samoa tsunami that caused around 2000 casualties (Satake, Rabinovich, Kanoglu, & Tinti, 2011), all displayed a failure of co-ordination and management which resulted in delayed evacuations and poor emergency responses.

In these complex and dynamic situations, the high volume of diverse information from multiple sources can readily lead to overload and make it difficult for emergency managers to relate the information to the prevailing situation. In addition, the raw information may need further transformation to make it applicable to the different roles, objectives and tasks of the emergency managers – an unwelcome overhead when time is of the essence and stress levels are high. In addition, the different managers in the emergency centre(s) must share information and co-operate in their decision making to achieve overall as well as local objectives.

This chapter contains a complete literature review on emergency management, emergency decision making, and information systems support in emergency decision making and related concepts. It focuses on systems for mass evacuation, the central role of situation awareness and the contribution of ontologies to systems design. On the one hand, this chapter describes the basic knowledge necessary to understand the purpose of this thesis, and on the other hand, it discusses some similar research studies to highlight the missing literature and establish how this work is different.

## 2.2 Emergency Management

An emergency is defined as an abrupt and unforeseen event endangering the safety of people, property or the environment that compels instant action (Cronan, 1998). An emergency is also a threat to the basic structures or the fundamental values of a social system, which requires making critical decisions under time pressure and highly uncertain circumstances (Rosenthal et al., 2001). These definitions apply to all types of emergency situations. Emergency management is defined as the planning for, and the execution of, all emergency functions necessary to mitigate, prepare for, respond to and recover from emergencies and disasters (FEMA, 2007).

Emergency management deals with risk mitigation, response and recovery. It is also defined as “a range of measures to manage risks to communities and the environment” (AEMI, 2008). Some emergency management frameworks are as follows:

New Zealand: The National Civil Defence Emergency Management Planning has the 4R approach to EM comprising of Reduction, Readiness, Response and Recovery (MCDEM, 2009).

Australia: The national government considers EM as Emergency Risk Management, Disaster Mitigation and Consequence Management (AEMI, 2008).

United States: The Federal Emergency Management Agency (FEMA) has defined a very detailed EM strategy for both public and business. In general, it ranges from mitigation to response and recovery (FEMA, 2007).

Canada: Canadian EM framework covers Prevention and Mitigation, Preparedness, Response and Recovery (PSC, 2011).

Almost all of these definitions introduce four functional phases namely; Mitigation, Preparedness, Response and Recovery in emergency management. All these functions are discussed in more detail in the upcoming sections. The complexity and importance of emergency management activities have been illustrated in recent disasters such as the 1995 Kobe Earthquake, the 2004 Sumatra Earthquake and tsunami, the 2005 Pakistan Earthquake, the 2005 Hurricane Katrina, the 2010 Haitian Earthquake and the 2011 Japanese Earthquake and tsunami. All these disasters bring to light the vast range of situations to be considered while planning emergency management and the constraints in existing practices, procedures and systems.

### 2.2.1 Emergency management in the context of mass evacuation

The mass evacuation of an area is needed when a natural or technological hazard threatens and risks the safety of those within the area. Mass evacuations can also be needed following the impact of a hazard which has subsequently made the area unliveable. Evacuation becomes necessary when the benefits of leaving outweigh the risk of sheltering-in-place (MCDEM, 2008a). There are two main options available to emergency managers to direct people, when considering ordering an evacuation; 1) shelter-in-place, and 2) evacuate. These two options can be used separately or in combination to provide the most effective response to the circumstances of a specific event (MCDEM, 2008a).

Shelter-in-place: This option requires people to remain in their current location, e.g. home, office etc. Shelter-in-place is necessary when the nature of a hazard shows that leaving would place people at greater risk. It also carries the benefit that people generally recover from an emergency situation faster in familiar areas. Dangers that may need shelter-in-place include (MCDEM, 2008a):

- Toxic chemical spill
- Radiation release
- Act of terrorism
- Pandemic
- Volcanic ash fall

Evacuation: Evacuation becomes necessary when the benefits of leaving outweigh the risk of staying. This option means asking or directing people to leave their current, potentially dangerous location and providing help to them in the form of transport, shelter and the other necessities of life. Evacuees should be kept as near to their homes as possible. Hazards that may require evacuation include (MCDEM, 2008a):

- Tsunami/hurricane/tornado
- Flash flooding
- Riverine flooding
- Volcanic activity (other than light ash fall)
- Landslip/landslide
- Wildfire

- Lifeline utility/infrastructure failure

Evacuation may take place before or after an event. Evacuation can be further classified into two types: voluntary evacuation, or mandatory evacuation. Mandatory evacuation is instructed when risk to the residents is imminent and it is highly dangerous to remain where they are, whereas voluntary evacuees leave their current location because of actual or perceived risk without being directed to do so. Volunteer evacuation is beneficial in a sense that emergency managers can concentrate only on those people who need assistance for evacuation.

Evacuees from the areas outside the evacuation zone who leave despite the fact they are not threatened are also referred to as “shadow evacuees”. This situation can pose significant problems, e.g. unnecessary traffic congestion, which will also delay or stop the actual evacuees from reaching safe ground. On the other hand, in the case of severe weather conditions, shadow evacuees can put themselves in greater danger than if they remain where they are.

Depending on circumstances, the shelter or evacuation options can be used separately or in combination to provide the most effective response. Figure 1 shows the sequential phases of emergency management (MCDEM, 2008a).

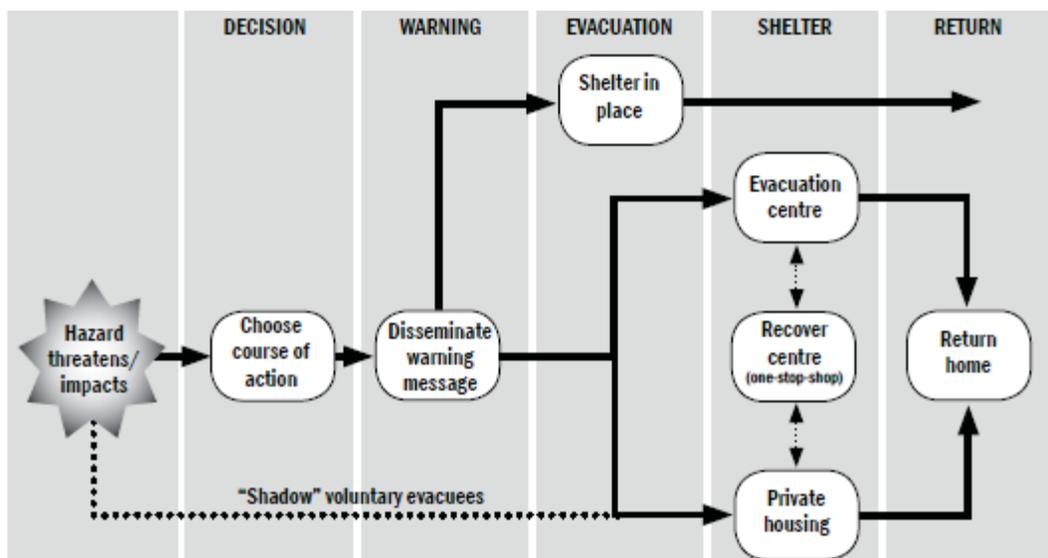


Figure 2.1 Phases of evacuation (MCDEM, 2008a)

- Decision to order an evacuation: The decision phase constitutes the period when data from the field is processed and a choice is made whether to order an evacuation or advise people to shelter-in-place.
- Warning: During this phase, notifications are issued to the public, which contain an explanation of the situation and recommendations.
- Evacuation: This phase describes the actual physical movement from an area
- Shelter: This phase occurs when evacuees are accommodated in welfare camps. This phase usually includes the registration process, accommodating evacuees and assessing the provision of welfare and recovery requirements.
- Return: This phase involves co-ordinating the physical return of evacuees to their homes following an assessment of the evacuated area and issuing an all clear.

The duration of each phase differs according to the nature of the hazard, as do the emergency management activities and the requirements of decision making. For most emergency events, evacuation typically starts at the local level and then escalates as the impact of the hazard spreads. Similarly, whilst local authorities deal primarily with local community needs they must share situation information and resources and co-ordinate planning with national authorities. Mass evacuation cannot be executed by a single agency or organisation in isolation. Co-ordination between all the relevant stakeholders is important before and during all phases of evacuation. The number of organisations or stakeholders and their activities related to mass evacuation depends directly on the following factors (MCDEM, 2008a):

- Geographic size of the region
- Regional topography
- Regional hazards and vulnerabilities
- Demographics
- Size and density of population
- Resources available

As the number of organisations increases, effective communication and co-ordination between them becomes very complex and challenging. The next section presents an

example of a tsunami scenario to illustrate the planning, information sharing, and decision making processes for successful mass evacuation.

### 2.2.2 Mass evacuation in case of tsunami

A tsunami is a series of waves that can move on shore rapidly, last for hours and flood coastal communities with little warning. Tsunamis can be triggered by a variety of geological processes such as earthquakes, landslides, volcanic eruptions or meteorite impacts (National Research Council, 2011). Since 1800, when modern record keeping started, tsunamis have taken many lives around the world. The threat of a potentially catastrophic tsunami on coastal areas looms in seismically active regions in the Pacific and Atlantic (Figure 2.2) (National Research Council, 2011). Recently, tsunamis generated by earthquakes in West Java (July 2006), Samoa (September 2009), Chile (February 2010) and Japan (March 2011) have flooded coastlines worldwide, highlighting the need for a focused and well-co-ordinated effort to minimise the loss of life and property. Tsunamis happen rarely enough to allow a sense of a false alarm, but when they do occur there may be just minutes or hours for people to reach a safer location National Research Council, 2011).

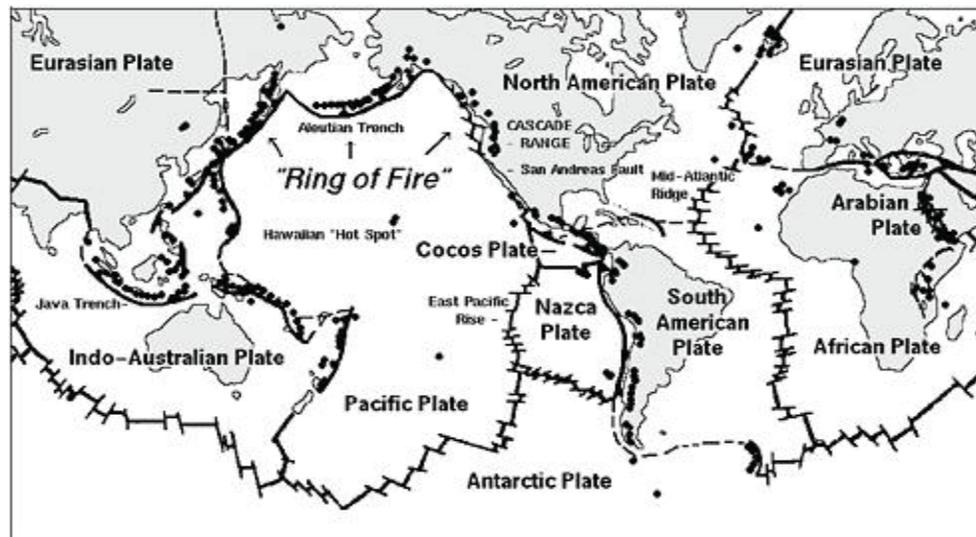


Figure 2.2 Threat of a catastrophic tsunami on coastal areas of Pacific and Atlantic (source: USGS<sup>4</sup>)

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<sup>4</sup> [http://vulcan.wr.usgs.gov/Images/Gif/PlateTectonics/Maps/map\\_plate\\_tectonics\\_world\\_bw.gif](http://vulcan.wr.usgs.gov/Images/Gif/PlateTectonics/Maps/map_plate_tectonics_world_bw.gif)

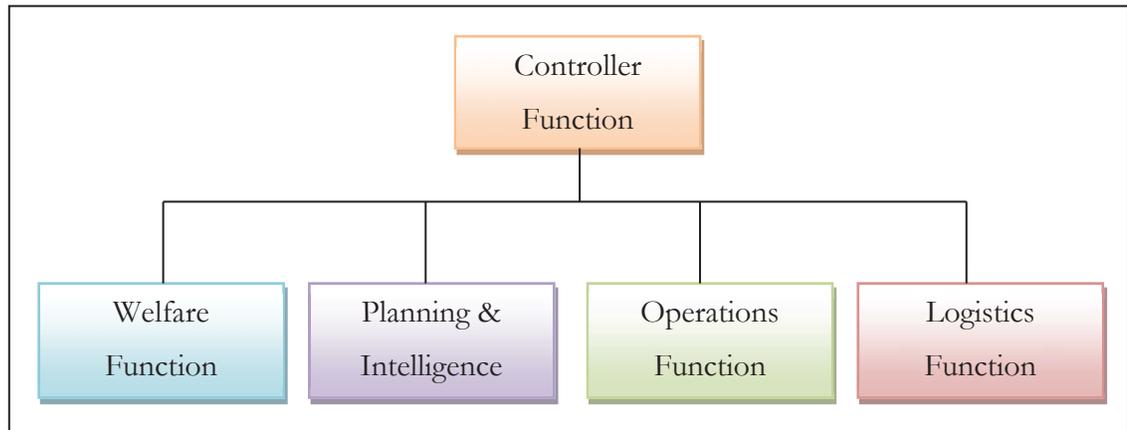
A timely evacuation decision and the successful evacuation of people from an area at risk can save many human lives. Making a right and timely evacuation decision is based on the right interpretation of incoming situation information. Similarly, the decisions which task an emergency manager should carry out at the particular phase of an emergency depend on the goals and objectives of his/her role. Once received, the information is synthesised and interpreted to make sense of it. The decision is then made whether to evacuate or not. Once the requirement for evacuation is confirmed, a decision is made about the time to start evacuation. For this decision, seismic, Deep-Ocean Assessment, and Reporting Tsunami (DART) data, along with the information on the characteristics of potential areas to be evacuated and available resources to complete the task are required.

Moreover, an overlap in the understanding of a situation is required by emergency managers to achieve a consensus so that the evacuation decision can be made as quickly as possible. This overlap is achieved by sharing and discussing situational knowledge amongst the emergency team members. Once a decision is made, co-ordination among several organisations is needed to implement the decision. On a macro level, each of these organisations should know which organisation needs to co-ordinate with them about “what they are doing” and “what they need from them” and vice versa. On a micro level, individuals should know which of their team members are dependent (need information or require some actions to be performed) on them and vice versa. Without this knowledge, organisations and individuals will not be able to co-ordinate their activities to achieve the overall goal.

### **2.2.3 Emergency management in New Zealand**

In New Zealand, the National Crisis Management Centre (NCMC) looks after a crisis at national level and co-ordinates with the regional emergency offices known as Group Emergency Operation Centres (GEOCs). GEOCs, in turn, co-ordinate with local Emergency Operation Centres (LEOCs) within that region. Co-ordination between NCMC and GEOCs and LEOCs is critical for decision making, as most of the major decisions are made by NCMC and implemented by LEOCs in co-ordination with supporting organisations such as the Fire Service, Police etc. New Zealand uses Co-ordinated Incident Management System (CIMS) for managing the response to an incident involving multiple responding agencies. CIMS has five basic functions: Controller, Planning & Intelligence (P & I), Operations, Logistics and Welfare. In all

emergency operation centres, including NCMC, GEOCs or LEOCs, these functions exist either in the form of sub-teams or individuals, depending upon their scale of responsibilities as shown in Figure 2.3.



**Figure 2.3 CIMS Structure of LEOC, GEOC and NCMC (MCDEM, 2009)**

The P&I function is responsible for forecasting the incident development, anticipating likely needs, and drafting the Incident Action Plan. This role of the GEOC has a strategic scope. The Operations function enacts the Incident Action Plan, which makes sure that responders are as focused and aware as possible so they can fulfil the objectives set by the Controller. The Operations Manager is generally responsible for the operational command of resources. This means allocating specific functions to agencies in their areas of expertise, monitoring their performance and providing a communication link between the responders and the other elements of the GEOC, especially Logistics. The Logistics function or Manager ensures the continuity of operations by making sure there are sufficient resources on site and within GEOCs. The Welfare function is responsible for the wellbeing of affected people during or after the emergency situation, especially in the case of evacuees. They set up temporary welfare camps and provide accommodation, food and basic medical facilities until required. The Controller is responsible for the overall incident progression and has overall accountability for the incident. Moreover, the controller function approves the Situation Reports (SitReps) and Incident Action Plans (IAPs) issued by the GEO.

Clear information sharing procedures and response prioritisations help in achieving a co-ordinated management of an emergency. Consistent emergency management requires information sharing among involved organizations along with specific event

needs and priorities. Reliable information flows and proper prioritisation take place when organisations are well aware of the procedural platform to be used in emergency response and critical information required to make decisions is available. Hence, information requirements for the functions illustrated in Figure 2.3 for decision making and carrying out their tasks is vital for the successful evacuation.

## 2.3 Emergency Decision Making

### 2.3.1 An overview

Decision making is the cognitive process of selecting one choice out of a set of choices (Grant, 2009). The process starts when a task is to be done, an action is to be taken, a goal is to be achieved or a need is to be fulfilled, and different options exist to carry it out. It ends when the decision maker has selected an option. The decision maker can be an individual, a team, or a coalition of organisations. In emergency response, an option is usually an intended course of action, with actions occurring serially or concurrently (Grant, 2009). Below are some of the important factors which affect emergency decision making.

**Emergency decision making is different:** Decision making during emergency situations differs from ordinary or business decision making. Because lives and infrastructure may be at risk, stress levels are high, available time is short, the situation is continuously evolving and often information is incomplete and sometimes conflicting. In these circumstances, rapid situation assessment is a key pre-requisite for making appropriate decisions. Salas et al., (1995) describes this as a cognitive process in the situation assessment that provides the integration and understanding of information and temporal processes in which the experiences are used to predict the future. Stress being a conspicuous feature of emergency decision making, the degree of stress must also be linked to the process and outcome of emergency decisions (Bond & Cooper, 2005).

**The role of stress:** Stress is defined as a psychological factor that threatens the individual's physical and psychological well-being and increases the individual's responsibility for the successful task performance (Driskell & Salas, 1991). Berkum (1964) attributed the decrease in working memory, where all the information is encoded for processing, as the cause of decreased performance under stress. Hence, excessive stress significantly reduces the human capability for information processing (Keina & Friedland, 1984). Fiedler and Garcia (1987) argued that decision performance is

influenced by the individual's cognitive resources, level of intelligence, experience and technical expertise, which in turn are influenced by the degree of anxiety or stress. Task complexity and team support also have an influence on the decision outcome (Fiedler and Garcia, 1987).

**The role of experience:** Decision making is based on a concept, an understanding and identification of the general requirements of the situation (Stevens & Campion, 1994). Klein (1989) defines the stages of decision making as feature matching, situation assessment, mental simulation of actions performed in similar past situations, and the outcome of action. Wickens (1992) argued that decision making is based on a decision maker's experience and an increased ability to assess risk. Therefore, even if a situation is evolving, an experienced emergency manager is more able to recognize, interpret and integrate the new information and make the decisions about how the response should proceed. Klein (1989) found experienced people were making choices based on their prior experiences and their ability to recognise or classify a situation based upon the critical cues from the environment and their goals and expectations from typical actions. The most successful decision makers were the ones with a good understanding of their goals and recognised the prominent features of the situation. They recalled a single course of action based on the recognition of situations and evaluation of the options by mental simulations to assess the outcomes (Bond & Cooper, 2005). However, this model cannot be applied when a previous situation is not completely remembered.

**The role of available time:** In emergencies, the tendency to make decisions faster makes them more prone to errors. Therefore, the stress level is also high when decisions are required in a short time period. Emergency situations are characterised by dynamic and evolving conditions, role uncertainty and complex situational constraints. Some of the several factors that contribute to this complex process are the unique attributes of disasters, rarity of disasters and less time during the disaster to understand and to obtain the experience necessary for emergency response. These problems are highlighted from the perspective of information management and decision making within integrated emergency management environments (Paton & Jackson, 2002). Emergency management needs to deal with these characteristics by delegation, communication, decision making and inter-agency co-ordination.

**The role of co-ordination and collaboration:** Inter-agency communication is important for effective decision making (Paton et al., 1999). In large scale emergencies, like the risk of a tsunami, a team of various individuals is involved in decision making. These individuals are usually from different backgrounds with different expertise and experience. Moreover, many of their objectives differ, depending upon their roles in the overall emergency management. Therefore, understanding the situation in a right and similar way is a challenge. Implicit information gathering is more effective if team members have a good understanding, not only of their own information needs, but also the needs of the fellow team members who depend on them for information sharing. Hence, for effective multi-organizational and multi-disciplinary co-ordination and performance, a team mental model is very important to provide the information required to achieve the common goal. With a team mental model, an implicit knowledge of activities and procedures called tacit knowledge exists within a team (Paton & Jackson, 2002). Tacit knowledge permits people to learn from their experience and to apply their knowledge in a goal-directed manner (Sternberg et al., 2000). Tacit knowledge also improves a person's adaptability to the changing environment. Therefore, it is an important component of effective performance in evolving, uncertain and complex emergency situations.

**The role of explicit and tacit knowledge:** The knowledge requirements for emergency decision making, as identified by Wang and Rong (2007), include explicit emergency knowledge sources and the agility of emergency knowledge support and features. The emergency knowledge sources include emergency environment information, contributing emergency incidents and emergency documentation. As the emergency knowledge required for decision making comes from diverse sources, it requires decomposition, matching and integration. The sources mentioned by Wang and Rong (2007) are quite important, but these authors ignored the other forms of knowledge, e.g. tacit knowledge (Paton & Jackson, 2002) which is experiential and obtained from exercises, trainings and simulations or from knowledge created about fellow team members' work and their shared mental models.

Thompson and Dowding (2002) propose the following factors as the most critical for the decision making process.

- The decision maker's ability or cognitive resources

- The decision maker's situational awareness (SA)
- Level of stress
- The difficulty of the task or its complexity
- Level of team support

These factors are strongly inter-dependent. For example, when a task is difficult or complex and the decision maker has a lack of situation awareness, the stress level rises (Sinha, 2005). Similarly, providing a higher level of team support can reduce high stress levels. The excessive stress also affects a decision maker's ability to process information by reducing the short term memory (cognitive resource). Hence, situation awareness and team support can be improved to reduce the stress factor, ultimately improving the decision maker's ability to make better and informed decisions. These issues are further discussed in subsequent sections.

### **2.3.2 Models of emergency decision making**

In business, strategic leaders make critical business decisions after several hours or days of thinking through the options, and carefully evaluating each in turn against their business objectives using decision analysis methods. This is the classic method of decision making in which decision makers are trained to evaluate various options. However, in a dynamic and time critical situation, when a decision is needed quickly and many lives and infrastructure are at stake, the classical method of decision making fails. Usually there is not enough time to gather complete data and evaluate all possible options. Therefore, in emergency situations, people do not consciously evaluate options, but they know "what is the right thing to do" (Flin, 1996). This can be called intuition, but when it comes to the judgements, highly complex mental activity happens in the mind of an individual. However, a question arises - can decision making in such critical situations be left for intuition and judgements alone. We will come back to this discussion later; let us first look at the two main categories of decision making (Kobus et al., 2001):

- Intuitive or Naturalistic Decision Model
- Analytical or Rational Decision Model

It is argued by Klein (1997) that in an emergency situation decision makers select the best course of action based on their job role, experience and the situation in hand,

whereas in less stressful conditions decision makers tend to evaluate different alternatives (Orasanu & Connolly, 1993). Decision making techniques in an emergency context usually deal with cognition by using knowledge, experience, logical reasoning and mathematical analysis etc.

State of the art works (Albert & Steinberg, 2011; Downs & Fischhoff, 2009; Luce & Winterfeldt, 1994; Reyna & Rivers, 2009) describe decision models as normative, prescriptive and descriptive. Normative models describe how decisions should be made. Prescriptive models describe how decisions could be made and take a rationalist view based on decision analysis. In contrast, descriptive models describe how decisions are made from either an interpretive or a naturalistic perspective. Interpretive process includes hypothetical-deductive processes (Thompson & Dowding, 2002) which vary depending on the situation and expertise cognitive continuum (Hamm, 1988).

In an emergency management context, these decision models are based on the classic frameworks such as Observe-Orient-Decide-Act (OODA) cycle (Boyd, 1987), and Decision and Learning Cycles (DLC). Both of these theoretical frameworks provide the necessary flexibility to understand emergency decision making (Simon, 1955).

Normative decision model aligns with classical decision theory. According to this model, the decision maker is believed to be a fully informed rational person who examines a set of options, or course of actions, and weighs various attributes in order to make the best choice. The more recent naturalistic decision model describes complex cognitive functions, which can work in highly demanding situations such as those having:

- Short time
- Uncertainty
- Unclear goals
- Team and organisational expectations
- Dynamic situations
- High stakes like lives and infrastructure.

The usual methods provided by the normative decision making i.e. deductive logical analysis, evaluation of probabilities and statistical methods do not seem as useful during highly stressed emergency situations due to a limited short term memory (Kaempts et al.,

1993; Klein, 1998). Normative decision models are more useful for well-defined problems in which there is plenty of time to evaluate options under limited stress (Endsley & Jones, 1997). The following sections summarise the fundamentals of these decision models and their suitability for emergency decision making.

### **2.3.3 Intuitive or Naturalistic Decision Model**

Classical decision making is primarily built around analytical and heuristic approaches to decision making (Hutton & Klein, 1999). It is argued that being largely normative instead of descriptive leads to failure in capturing critical aspects of how experts actually make decisions in emergency situations (Endsley et al., 2007). Naturalistic decision models (NDM) remain the most cited and popular in most of the cognitively demanding situations (Sinha, 2005; Endsley et al., 2007). The distinctive feature of naturalistic decision making is that the decision makers are highly proficient and experienced in their domain (Elstein, 2001). Expert decision makers use the situational assessment, which makes use of signal encoding, goal assessment, expectancy checks and appropriate actions; a rapid encoding of stimuli based on experience and decisions are rule based rather than knowledge based (Flin et al, 1996).

NDM research has been done for a variety of domains such as nuclear power plants (Roth, 1997), commercial and military pilots (Amalberti & Beblon, 1992), fire emergencies (Klein, 1999; Klein & Klinger, 1991) air traffic control (Rodgers et al., 2000). Although these domains are contextually different, they are also similar in many ways e.g. uncertainty, complexity, significant consequences, lives at risk, competing goals and time constraints (Zsombok & Klein, 1997). The Recognition Primed Decision (RPD) model was introduced to explain the NDM process during complex situations (Klein et al., 1986; Klein, 1989; 1993). The use of RPD is evident from many emergency situations in which the response also requires the appropriate assessment of a situation for decision making. The RPD model focuses on situational assessment rather than option assessment, stressing the significance of experience in decision making and relying on 'satisfactory' or 'good enough' decisions (Simon, 1989). Such decisions are likely when time pressure is high. However, it is clear that good decisions are dependent on experience and expertise. Situation recognition allows the decision maker to classify the tasks as well known. The familiarity carries with it the recognition of the following types of information:

- High priority goals (*Examples: evacuating the areas which are under high and instant risk first*),
- Cues to monitor (*Example: speed, direction and height of tsunami waves at different time instances and locations*),
- Expectations about the unfolding situation (*Example: expected height of wave at certain locations, expected arrival time of first wave on certain locations*).

According to Klein and Klinger (1991), the RPD model can be summarised as follows:

- Options are generated consecutively, and the more usual course of action is considered first.
- Option evaluation is also performed consecutively to analyse the adequacy of the option and to identify possible problems and solutions for them.
- The RPD model includes facets of problem solving and evaluation along with decision making.
- Experienced decision makers are able to respond quickly by identifying a tested course of action at the start, rather than generating and evaluating a large set of options.

The RPD model works in three possible ways (Klein & Klinger, 1991). The simplest way of RPD working is when the situation is recognised successfully and the respective obvious reaction is implemented. A more complex way is applicable when the decision maker consciously evaluates the reaction, using imagination to uncover problems prior to carrying it out, and minor changes are made to the course of action. In the most complex case, the evaluation reveals problems, which require modification, or the option is judged to be flawed and is rejected in favour of the next most usual useful reaction.

#### **2.3.4 Rational or Analytical Decision Model**

A rational decision model (RDM) is used when the best immediate option is selected (Simon, 1955) by a decision maker who is called the rational decision maker. The word “best” shows that the decision is, or should be, most favourable. According to Grant (2009), to find the best option, each one of the complete set of possible options must be given a score, then the set must be ranked based on this score, and the highest-ranking option is selected. The score given to an option is composed of the values of its

attributes. Hence, RDM requires that the decision maker must have perfect information about the values of all attributes of all the possible options. The word “immediate” means that the decision maker considers the current problem is influenced neither by any related decisions made in the past nor by any possible future consequences of this decision (Grant, 2009). Hence, this model rules out using any knowledge gained from previous experience to make decisions and RDM research focuses on the option selection. This is based on some judgment or logical plan such as the maximisation of the expected value or the removal of options by features or aspects (Dastani et al, 2003).

The selection of best decision makes RDM attractive at first. However, it also has some limitations. Knowledge about RDM has been largely gained by performing experiments in laboratory settings using immature subjects (Klein, 1998). As we know, the rational decision maker must have a perfect knowledge and when the number of options and their related attributes is large, the process may take a substantial amount of time and resources. The description of RDM shows that any system, which is designed for supporting rational decision making, should have the following properties (Grant, 2009):

- A set of known options with their attributes;
- A mechanism for obtaining the values of the attributes;
- An algorithm for computing each option’s score from its attribute-values;
- An objective method for selecting the highest ranking score.

The lengthy and tiring nature of RDM means that it is applicable to domains in which the goals are well defined, the environment changes slowly, no other active agents are present and enough time is available to evaluate all available options, which makes it very inadequate to be used during emergency situations that require the opposite.

The limitations of pure NDM and RDM can be minimised by combining the two approaches. Bryant (2002) also proposed a synthesis of NDM and heuristic approaches to overcome the limitations of pure NDM. However, to date very little research has been done combining both classical and naturalistic paradigms to explain decision making in complex situations. This literature gap is being addressed in the current study; we are considering computer support for combining these paradigms - more details of this combined approach will be provided in upcoming chapters.

## **2.4 Situation Awareness (SA)**

The first step in any decision model is understanding what is going on. This understanding is required by the decision maker to suggest tasks that can achieve a decision's objectives. A decision maker's assessment of a situation results in a product called Situation Awareness (SA) (Endsley, 1995b). The SA has emerged as a key cognitive construct of interest, formed from the terminology and challenges of the aviation field (Endsley et al., 2007). For an operator, SA is a mental representation of the world around him/her at any given point of time. In simple words, SA is about knowing and recognising what is going on around us (McIlvaine, 2007). It is required for moment-to-moment decision making and improved performance in complex systems (Endsley, 1988a). Nowadays, SA research has been extended to many other sectors like air traffic control, nuclear and petro chemical plant operation, military contexts, driving aviation, emergency response (Endsley, 2000; Stanton et al., 2005).

### **2.4.1 SA definition**

SA has several definitions. For example, according to Smith and Hancock (1995) it is an externally directed consciousness that directs actions in a dynamic tasks environment. Whereas, according to Dominguez (1994) SA is also integration of information with previous knowledge to form a coherent mental picture and anticipating future events. In contrast, Taylor (1990) believed, SA is the knowledge, cognition, and anticipation of events, factors and variables affecting the safe, expedient and effective conduct of the mission. Sarter and Woods (1991) defined SA, based on the integration of knowledge resulting from recurrent situation assessments, but did not explain situation assessment. Other researchers have proposed alternative definitions of SA (Adams et al., 1995; Billings, 1995; Durso and Gronlund, 1999; Stanton et al., 2005; Salmon, et al., 2008). The range of definitions arises in part from the complexity of different cognitive models and in part from alternative views that emphasise particular features of a situation. Also, some definitions are broad, whilst others try to present a structured interpretation of the assessment process.

Therefore, SA has a range of theoretical connections emanating from the work of Adams et al. (1995), Smith and Hancock (1995), and Endsley (1995). A universally accepted definition for SA has consequently yet to emerge (Stanton et al., 2005) but two theories of SA – the three level theory of Endsley (1995) and the perceptual cycle model proposed by Smith and Hancock (1995), have emerged as dominant (Stanton et al.,

2005). Endsley's (1995) definition of SA has been applied in many domains (Wickens, 2008) and has become the most frequently used and extensively cited theory in the field (Albers, 1998; Klein, 2000; Son et al., 2007; Stanton et al., 2005). Moreover, Endsley has presented the best information processing approach compared with other models (Stanton et al., 2001).

#### **2.4.2 Endsley's three level model of SA**

SA has been entailed as playing a conspicuous role in several emergency decision making strategies (Endsley, 1995a; Endsley, 1995b). According to Endsley (1995b), SA is a key facet of effective emergency decision making and operational performance. SA is mostly defined in operational terms. For a given operator, SA is defined in terms of goals and decision tasks for some specific job (Endsley, 2000). A formal and widely accepted definition of SA that has been found applicable across a wide variety of domains is therefore:

*“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” (Endsley, 1988a).*

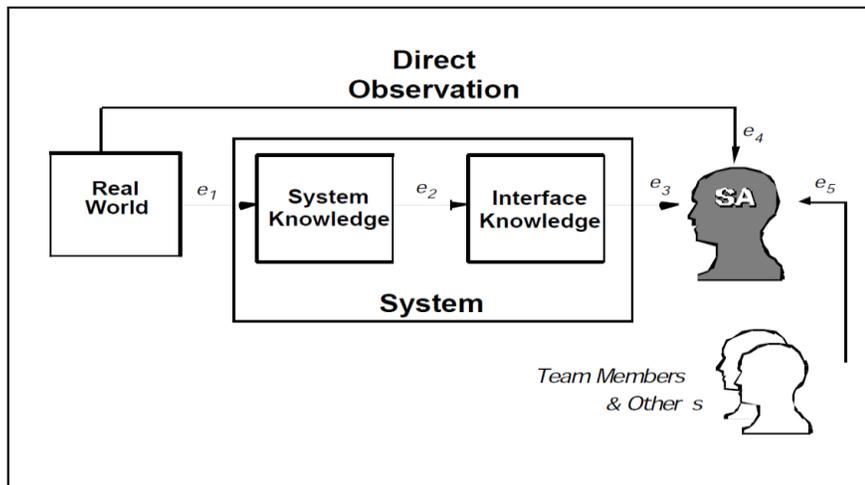
*Perception* is the first level of SA, it means understanding the importance of information about any situation. For example, in the context of a tsunami; earthquake magnitude, source location, depth and wave height and direction, if the earthquake source is in the water are critical attributes.

*Comprehension* is the second level of SA, it constitutes how people combine, interpret, store and retain information. Comprehension also includes integrating multiple pieces of information from SA Level 1 and determining their meaning and relevance to the operator's goals. For example, combining the earthquake magnitude with the geographical co-ordinates of an earthquake source, determines whether the earthquake is powerful enough and offshore to cause a tsunami or not. Moreover, processing the wave height information, if the source is offshore, it can be used to determine whether a tsunami has been generated or not.

*Projection* is the third and highest level of SA; it is the ability to forecast future situations from existing and previous situations. This ability allows timely decision making to counter any future risk. For a tsunami, forecasts would include predicted wave heights on arrival at the coasts, arrival time of waves, indication of areas under threat etc.

SA is critical to optimal decision making, but there are many other factors which play an important role. Klein's work in the area of Recognition Primed Decision making provides strong evidence for the impact of situation recognition/classification and associated action selection (Klein, 1989; Klein, Calderwood & Clinton-Cirocco, 1986). The relation between SA and decision making is also discussed by Adams et al. (1995) and Smith and Hancock, (1994). SA informs decisions and SA is formed by feedback from decisions. Therefore, SA, decision-making and performance can be theoretically perceived as distinct stages that can affect each other and can be decoupled through other factors (Endsley, 2000).

Endsley (1995b), as shown in Figure 2.4 below, explained sources of SA information. Decision makers can directly observe the situation and they can use technology or systems e.g. internet, telephone, radios etc. or group members to collect subsets of available information. Decision makers perceive and interpret information that results in SA.



**Figure 2.4 Information sources of SA (from Endsley, 1995b)**

Although SA has a very significant impact on decision making, good SA does not guarantee optimal decisions (Son et al., 2007). Many other factors such as a change in the situation before the implementation of a decision, strategy, experience, training and personality, organizational and technical constraints may also affect the decision making process (Endsley & Garland, 2000). However, during emergencies, even experts can make incorrect decisions due to insufficient SA at different levels (Son et al., 2007).

## 2.5 Situation Awareness in Collaborative Systems

In larger events, several organisations are involved in emergency management processes so that the co-ordination of decision making is a challenge. Team members have different characteristics such as cultural background, environment, educational background, experiences and goals, depending on their roles, and it can be difficult to draw together individual expertise to handle a problem. Therefore, understanding the situation correctly and in a shared, common way is difficult. In addition, in an emergency, information is frequently evolving, uncertain and incomplete so that information co-ordination<sup>5</sup> requires information to be current and available in a directly usable form for accurate team decisions.

Due to the major requirement of team work in current disaster management organisations, the concepts of shared and team situation awareness (SSA & TSA) are currently receiving enormous attention from both human factors community and disaster management (Fiore et al., 2003).

### 2.5.1 Shared Situation Awareness (SSA)

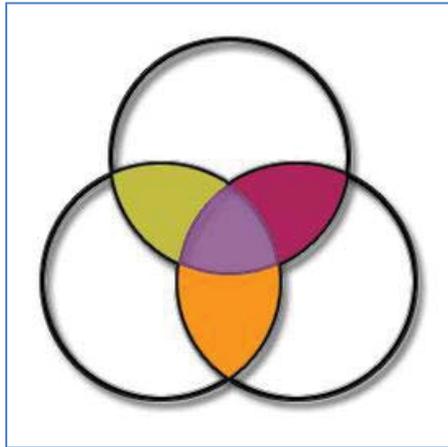
Shared Situation Awareness (SSA) refers to the extent of common SA requirements of team members (Endsley & Jones, 2001). Each team member has specific SA requirements for their task, some of which are common with their team member's requirements, and these researchers define SA as, "the degree to which team members have the same SA or shared SA requirements" (Endsley & Jones, 2001).

Moreover, Endsley and Robertson (2000) suggest that successful team performance requires that individual team members have a good SA of their own elements and the same SA for those elements that are shared. Thus, SSA refers to the overlap between the SA requirements of the individual team members. This concept is illustrated in the Venn diagram of Figure 3 where the circles represent each team member's SA requirements, and the overlapping segments depict the SSA (Endsley & Jones, 2001). The white areas of the circles indicate the information that does not need to be shared.

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<sup>5</sup> Co-ordination of people and organisations are also priorities in emergencies.

Sharing information that is not relevant to the SA requirements of other team members' roles would only create "noise" and wasteful effort to acquire it.



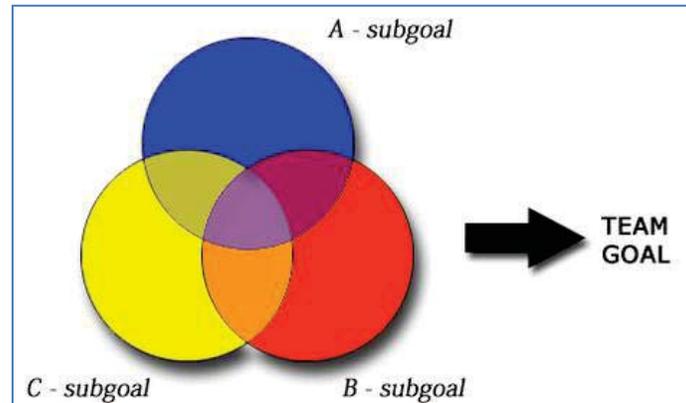
**Figure 2.5 Shared Situation Awareness (Endsley & Jones, 2001)**

### **2.5.2 Team Situation Awareness (TSA)**

A team is defined as “two or more people dealing with multiple information resources, who work to accomplish some shared goal” (Salas et al., 1995). Team Situation Awareness (TSA) is more complex than individual SA. Salas et al. argued that there is a lot more to TSA than just combining team members' SA. Moreover, due to the many other cognitive, social and team factors, research into the construct is challenging, scarce and difficult and there is no consensus on exactly how TSA works.

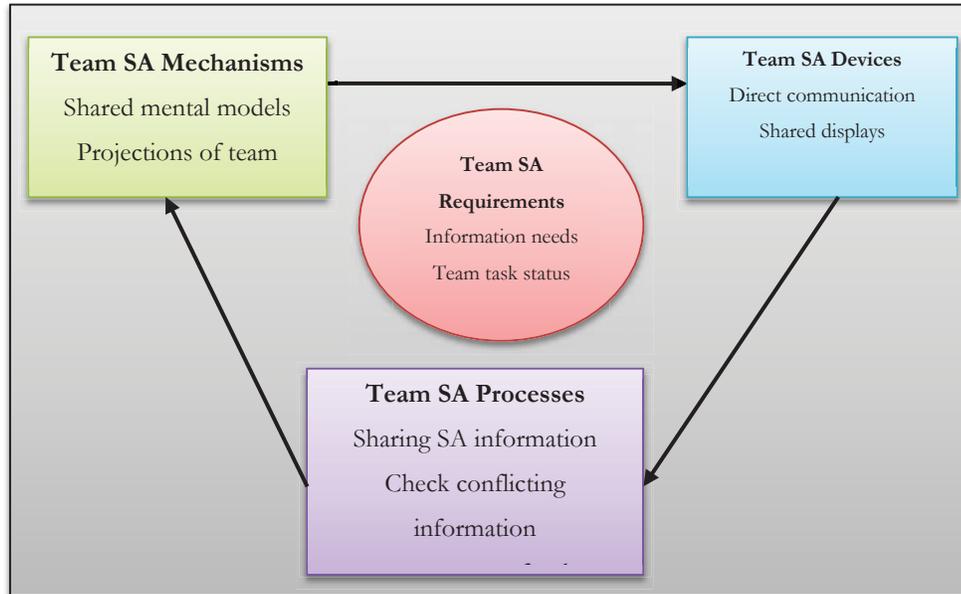
Taking an operational view, the most widely used model of SA due to Endsley and Jones (2001) leads to a definition of TSA as “the degree to which every team member possesses the situation awareness required for his or her responsibilities” (Endsley, 1995a). Endsley argues that the success or failure of a team depends on the success or failure of each of its team members. At its simplest level, therefore, each team member has a sub goal related to his/her role that feeds into the overall team goal. A set of SA information elements is linked with each member's sub goal and these are shared with other members of the team. The shared subset of information is the basis of team co-ordination which may occur directly or be mediated by technology (Endsley & Jones, 2001). TSA can therefore be represented as a Venn diagram (Figure 2.6) in which the circles represent team members' information relevant to their roles and the overlapping areas represent their shared information. A two-circle overlap denotes shared situation awareness (SSA) and the three-circle overlap signifies team situation awareness (TSA).

Teams with more than three members would clearly require diagrams with additional circles and multiple overlaps.



**Figure 2.6 TSA: the goals and SA requirements of all team members (Endsley & Jones, 2001).**

Endsley & Jones (2001) have extended their operational view in a model that describes the factors that help to build SSA and hence TSA (Figure 2.7). These factors – requirements, devices, mechanisms, and processes – facilitate interaction between the participants and the sharing of information so that teams can develop high levels of SSA and TSA.



**Figure 2.7 Factors that build high levels of SSA and TSA (Endsley & Jones, 2001)**

Taking a different perspective, Salas et al. (1995) have argued that there is a lot more to TSA than just combining team members' SA. Apparently, TSA is multi-faceted,

comprising an individual team member's SA, shared SA between team members and the combined SA requirements of the whole team. In this framework, TSA is mostly understood as a shared understanding of the same situation (Nofi, 2000) whereas, according to Perla et al. (2000), when we all understand a given situation in the same way it is SSA.

Salas et al. (1995) suggest that TSA comprises two important, but badly understood processes, individual SA and team processes, and depends on communication at various levels of SA. For example, perception of elements at level one SA is effected by communication of mission objectives, individual tasks and roles, team capability and team performance factors. Similarly, comprehension at SA level two is impacted by the interpretations made by other team members, so it is evident that sharing an individual's SA leads to the development or modification of another's SA. In addition, the mental schema limitations of an individual can be offset by information exchange and communications (Salas et al., 1995).

Salas et al. (1995) consequently defined TSA as “the shared understanding of a situation among team members at one point in time”, and concluded that “team SA occurs as a consequence of the interaction of an individual's pre-existing relevant knowledge and expectations, the information available from the environment and cognitive processing skills that include attention allocation, perception, data extraction, comprehension and projection”.

Another approach due to Wellens (1993) uses a model of distributed decision making to describe SA during collaborative activity and suggests that the key to TSA lies in the arrangement of teams to provide adequate separation for individual SA acquisition with sufficient overlap for co-ordination. Wellens (1989) defines TSA as the “sharing of a viewpoint between two or more individuals regarding current events in the environment, their implications and projected future”.

The TSA definition used in defining this framework is provided by Shu and Fruta (2005), which is:

*“Two or more individuals share the common environment, up to the moment understanding of situation of the environment, and other person's interaction with the cooperative task.”*

According to Shu and Furuta (2005), TSA includes two basic elements, an individual's SA and mutual awareness. Mutual awareness refers to the awareness that individuals of a co-operative entity have of each other's activities, beliefs and intentions. For example, if two team members A and B want to understand and act on a situation co-operatively, each of them needs to recognise the parts of the situation that he/she is responsible for, and to believe that the other member recognises their own parts of the situation and is willing to co-operate. In addition, each member must contribute a belief about the other team member's understanding. Hence, this definition covers both the individual and shared understanding of the situation and the execution of co-operative tasks. In short, for the team of two members A and B, A's TSA consists of three basic components (1) A's own SA, (2) A's belief about B's SA and (3) A's belief of B's belief about his/her own (A's) SA. If any of these is missing, the TSA is incomplete.

The complexity of interaction clearly increases with increasing team size and much work needs to be done to refine definitions and terminology, unravel interactions, and synthesise a complete picture of TSA. Only then, for example, will it be possible to answer questions such as "how much sharing of information (extent of overlap of circles, e.g. in Figures 2.5 and 2.6) is needed to ensure successful completion of a collaborative task in a given situation?"

## **2.6 Information System Support for Emergency Management**

Many researchers (e.g. Carver & Turoff, 2007; Jennex, 2007; Manoj and Baker, 2007; Turoff et al., 2004; Turoff, 2002) have concluded that in emergency situations, decision making is improved by dynamic information retrieval, and sharing and presenting information in the right format, to the right person, at the right time. The faster the decision makers get the required information, the more effective their response will be (Van de Walle & Turoff, 2007). During emergency decision making, lives and infrastructure are at stake and the level of stress is very high so that the importance of an emergency response system to assist the decision making process becomes obvious (Bellardo et al., 1984; Jennex, 2007).

However, very few systems seem to contribute noticeably to the emergency decision making process (Van de Walle & Turoff, 2007). One fundamental reason is that systems are sometimes designed without considering the users (de-Leoni et al. (2007). Even when users are involved in the design and development there is often a lack of understanding of

human decision making requirements (Carver & Turoff, 2007). Carver and Turoff actually argue that an information system should essentially work as a team member to provide enough decision making support during an emergency.

### **2.6.1 Emergency information systems frameworks**

Bellardo et al. (1984) argue that an emergency response system should consist of several basic components; a database, data analysis capability, normative models and interfaces. However, this model fails to address issues such as consideration for emergency plan and emergency response infrastructure, co-ordination between multiple organisations, information integration from diverse sources, knowledge from past emergencies and integrating multiple systems (Jennex, (2004). Jennex (2004) extended the emergency response system model of Bellardo et al., (1984) to facilitate the effective communication and data management to avoid information overload and argues that under stress emergency decision makers need a system that does more than just provide data (Jennex, 2007).

Turoff et al. (2004) also acknowledged the necessity to improve the design and functionality of emergency decision support systems (EDSS) and developed a set of general supporting design principles and specifications for a “Dynamic Emergency Response Management Information System” (DERMIS). DERMIS addresses the communication and information needs of command and control staff. Based on the emergency experiences emergency managers’ needs, Turoff et al. (2004) also emphasise the system support for SA and suggest the use of templates that can be modified as needed. Lee and Bui (2000) also supported a template based emergency response system model where each template provides a standard set of placeholders or slots for representing the details of the activity. As these frameworks are only capable of providing decision support based on historical data or previous experiences, they lack providing support to process dynamic information or information processing in real time or in new situations.

Because of the in-depth need analysis of stakeholders related to the use of technology, Meissner et al. (2002) proposed detailed communication architecture to support a basic emergency situation. In an extension to their work, Meissner et al. (2006) introduced conceptual information systems architecture MIKoBOS, suitable for supporting three different levels of organisational hierarchy. Therefore, Meissner et al., (2002; 2006) also

highlight the importance of understanding the specific needs of emergency managers while proposing a system-based support for emergency management.

Courtney (2001) suggested a new decision style, as presented by the Singerian approach (Churchman, 1971), which incorporates other inquirers into the environment. The goal of the Singerian inquirer is to create verified common knowledge. Courtney (2001) recommended the use of this type of inquiring and unbounded system thinking (Mitroff & Linstone, 1993), to address the decision making in complex contexts. In the Singerian perspective, problem and knowledge domains are closely connected by bringing in the multiple perspectives or world views. The unbounded system philosophy apprehends the organisational (social) and individual (personal) viewpoints. All this leads to a novel decision making model which also discusses many other important aspects other than technical ones.

Hwang et al., (2007) introduced a mobile-based ad hoc information system architecture suitable for Community Service emergencies. de-Leoni et al. (2007) proposed a communication architecture known as “WORKPAD” to support decision making during emergency situations. “WORKPAD” is a design based on task requirements identified via a task analysis technique called Hierarchical Task Analysis in various emergency scenarios. However, “WORKPAD” does not support the individual needs and is limited to the common needs of team leaders. Kwan and Lee (2005) base their emergency response information systems architecture on a Global Information System (GIS), which makes use of information collected from intelligent transportation and building management systems. Neither of these technology-oriented studies has identified the contextualised end user requirements.

### **2.6.2 Emergency management information systems (EMIS)**

Much of the research on emergency decision support systems has focused on different technologies. Examples include - transportation security decision-making for emergency response (Yoon et al., 2008), intelligent mobile decision support for triage (Padmanabhan et al., 2006), advanced knowledge models to support environmental emergency management (Hernandez & Serrano, 2001), aggregating knowledge of geographically separate experts (Mendonca et al., 2000), flood emergency decision support system (Mirfenderesk, 2009), emergency decision support system (Cortes et al.,

2000), agent-based environmental emergency knowledge system (Liu, 2004), and expert system for chemical incidents (Yeh & Lo, 2004).

Other research has concentrated on improving communication technologies. Examples embrace work by Otim (2006), Rosen et al. (2002), Potter et al. (2007), Iakovou and Douligeris, (2001) and McGrath et al. (2003).

An ambitious venture, the ALADDIN project, aims to model, design and build decentralised systems that can bring together information from a variety of heterogeneous sources to take informed actions (Adams et al., 2008). The ALADDIN design considers some different aspects such as data fusion, decision-making, and machine learning etc. (Adams et al., 2008). Jang et al. (2009) and Lien et al. (2009) have proposed RISED, a “Rescue Information System for Earthquake Disasters” for response following an earthquake.

All these projects promote technology to support emergency decision making during various natural disasters. However, none of them can be said to adopt a particularly user centred approach to system design to understand end user requirements and to involve users centrally in system design and development.

In contrast, Gao et al. (2007) proposed a user-centric system in a project called AID-N (Massey et al., 2006) that seeks to identify the unmet needs of triage response teams for medical assessment in an emergency. Aziz et al. (2009) also adopted a user centred design to develop a prototype for use in fire rescue operations. More recently, Katuk et al. (2009) used a knowledge acquisition approach to involve responders in the design and development of a web-based prototype for response in the aftermath of a flood.

### **2.6.3 EMIS support for SA**

During emergency situations, as indicated, the information sources for each emergency manager that form their SA (and hence SSA and TSA) can be different depending on their role, goals, and tasks in hand (Son et al., 2007). The challenge is to integrate information rapidly from diverse sources, e.g. from direct observations of environment, team members, past experiences, emergency management plans etc. (Endsley, 2001) and present it in a useful way. In dynamic and time critical situations, it is usually not feasible to acquire SA only by direct observations from the environment (Son et al., 2007). In such circumstances, information systems can play a very important role in supporting

data collection, integration, processing, sharing, communication, and presentation according to the task requirement (Son et al., 2007). Endsley et al. (2003b) suggest that if an information system is designed to enhance the SA of its users, then such a system should take a user centred design approach. Some existing systems, which are based on SA requirements, are as follows.

Lanfranchi and Ireson, (2009) proposed a project named “WeKnowIt” that allows both emergency responders and community citizens to participate during flooding incidents. WeKnowIT is one of the few studies that recognises the importance of enhancing SA for better decision making during emergency response. However, the authors do not clearly explain their understanding of SA and hence the SA requirements captured were very generic.

“WIPER” is a prototype emergency response system capable of generating traffic forecasts and emergency alerts for engineering, public safety and emergency response personnel (Madey, et al., 2006). WIPER is an attempt to explore the possibility of improving SA using mobile phones. However, neither end user requirements are reported nor the method of capturing end user requirements is clearly mentioned.

Son et al., (2007) presented a comprehensive framework to ensure the effectiveness of disaster response operations. The framework aims at improving the SA while supporting collaboration among various civil engineers’ roles. The study focuses on interaction between multiple individuals with an ultimate goal to improve SA in complex environments. Though the study (Son et al., 2007) is focused on the role of civil engineers, the work explains how a high level of SA can improve performance in dynamic and chaotic situations.

Blandford and Wong (2004) recommend the SA-oriented system design for senior emergency medical dispatch operators. During their study, it was identified that ambulance operators work under extreme time pressure with high risks and have to make decisions with incomplete information. They adopted two strategies to understand user SA requirements; contextual inquiry interviews (Beyer & Holtzblatt, 1998) and critical decision method (CDM) (Hoffman et al., 1998) which are cognitive task analysis methods. As a result, a set of design guidelines for system displays to support emergency medical dispatchers was identified.

Prasanna et al. (2009) identified the information required for SA development during rescue and response operations in urban fire scenarios. Two techniques inherited from cognitive task analysis (CTA); Goal Directed Task Analysis (GDTA) and Applied Cognitive Tasks Analysis (ACTA) were combined to create a tool called Goal Directed Information Analysis (GDIA). Prasanna et al. (2009) successfully identified information requirements for all three levels of SA. Mock-ups were developed and validated but no performance test for the users was carried out to evaluate the usefulness of the design. However, the information requirements gathered based on SA were impressively detailed.

Ferreira et al. (2009) used a task analysis technique in the form of a game based tool to collect the end users' needs for developing SA during emergency situations on a highway. The technique used by Ferreira et al. (2009) is promising for acquiring very detailed user requirements although few were reported. In addition, usefulness of the technique and validity of identified requirements were not put to the test.

Thus, all these studies stress the importance of considering the end user needs while designing a system. These studies also highlight the complexity of extracting the user requirements operating in time critical and complex situations, and then emphasise the significance of choosing appropriate techniques to complete requirements elicitation. In an iterative process of design and development, most of these studies produced early prototypes. Some of the prototypes were also used to demonstrate feedback on the interfaces and display but none of them has been tested for the users' performance and the validation of identified requirements. The studies based on an SA-oriented design approach support the user centred design of systems and emphasise the importance of improving SA as an essential requirement for better decision-making in complex environments like emergency situations. However, it is often not clear from the published studies whether requirement elicitation applies to whole situations, specific tasks, roles, or contexts.

There is very little in the literature that endeavours to understand the comprehensive SA requirements of emergency managers who work in such complex domains and engage in the high level collaboration that is required within and between various teams. Similarly, little has been done on the design of systems while considering the requirements of the shared and team situation awareness. Furthermore, there is not a

single study that has recognised the impact of SA on decision making for large scale emergencies such as tsunami risk for a highly populated area or city. Given the rise in the reported incidences of massive tsunamis and earthquakes, it is also surprising there is very little empirical work on the design and development of SA oriented information systems specifically aimed at improving the SA of emergency decision makers for mass evacuations in these catastrophes.

## **2.7 Ontology**

### **2.7.1 Definition**

A parallel trend in emergency systems design within the past decade has been the use of ontological descriptions to model disaster scenarios and responses and attendant system design (Hoogendoorn et al., 2005; Little & Rogova, 2005; Liu & Fang, 2006; Wenjun et al., 2005). In philosophy, ontology is defined as: “*an explicit specification of conceptualisation*” (Gruber, 1993). Alternatively, Studer et al. (1998) define ontology as “*a formal, explicit specification of a shared conceptualisation*”. Conceptualisation refers to an abstract model of some phenomenon in the world by identifying the relevant concepts of that phenomenon. Explicit means the type of concepts used, and the constraints on their user are explicitly defined. The term ‘Formal’ refers to the fact that the ontology should be in a standard language, which is machine-readable. ‘Shared’ reflects the notion that ontology captures a consensus, that is, not the private idea of some individual but the accepted and shared understanding of a group. In practical terms, this means that an ontology is a structured set of concepts describing a specific domain of knowledge that can be used to create a knowledge base for that domain. As a “conceptualisation of shared knowledge”, an ontology can provide a common vocabulary that is equally understandable by all participants – a valuable asset when domain users follow different terminologies.

This means that ontology is a hierarchically structured set of concepts describing a specific domain of knowledge that can be used to create a knowledge base. Ontologies can be used for many different purposes and applications and they can be constructed and organized in many different ways (Albertsten & Blomqvist, 2007).

The information systems literature contains many definitions of ontology, some of which appear contradictory due to the use of different terms and loose application. One coherent and well-accepted definition (Noy & McGuinness, 2001) holds that an ontology

contains concepts (classes in ontological terminology), which have distinguishing features or attributes (slots) that impose constraints (facets) on their use. The relations between the concepts structure them into hierarchies according to various rules and axioms (Guarino, 1998) so that child concepts inherit (subsume) the attributes of their parents. An ontology, together with a set of individual instances of classes, constitutes a knowledge base. Though we will discuss the specific reasons to use ontologies in our system in later chapters, some of the general reasons to use ontology in information systems are as follows (Noy & MacGuinness, 2001):

- To share common understanding of the structure of information among people or software agents
- To enable re-use of domain knowledge
- To make domain assumptions explicit
- To separate domain knowledge from the operational knowledge
- To analyse domain knowledge

### **2.7.2 Ontology-based situation awareness (SA)**

Ontology is commonly understood on two levels: (a) as a knowledge base for a specific domain and (b) as a vocabulary, which uses appropriate terms to describe domain entities or agents, and the protocols for the relationships and interactions between them. Ontology therefore describes the domain knowledge and provides a consistent understanding that can be shared by users. If the domain is an emergency situation, then an ontological description can conceivably facilitate shared situation awareness.

Several studies (Mathues et al., 2003; McGuinness et al., 2003; Horney et al., 2003; Boury-Brisset, 2003) have proposed ontology based SA systems. They also provide higher level situation ontologies to capture generic situation descriptions that require more domain specific knowledge for implementation.

Ontologies provide considerable value in terms of data and knowledge acquisition, semantic integration (Baumgartner et al., 2008), semantic inter-operability and decision support. Moreover, ontologies provide the basis for a common semantic frame of reference for user groups from different backgrounds with different sub-goals that must operate in a collaborative way to achieve an overall larger goal. Ontologies are therefore,

considered a vital element of systems that aim to provide shared understandings of a domain and support shared situation awareness (Smart et al., 2005).

### **2.7.3 Existing ontology-based systems to support situation awareness (SA)**

Several major projects like “BeAware” (Baumgartner et al. 2010), “AKTiveSA” (Smart et al., 2005), “Information fusion for Natural and Man Made Disasters” (Rogova et al., 2006) have successfully used ontology-based SA in real-life situations. The importance of ontology-based information fusion for enhanced situation awareness has been explained by many researchers (Baclawski et al., 2003; Matheus et al., 2003; Matheus et al., 2004; Matheus et al., 2005; Sycara et al., 2003). Among these, Matheus et al. (2005) used ontology for formally defining situations. Based on their definition, they developed generic concepts that can serve as the basis for development of domain specific ontologies. They named the proposed system as situation awareness assistant (SAWA) as it is intended for enhanced situation awareness. SAWA also uses a number of semantic web technologies, namely Web Ontology Language (OWL), Semantic Web Rule Language (SWRL) (Fikes et al., 2003). The idea of SAWA is to provide a domain ontology that captures the objects and relationships of interest in a domain. The user controls the system situation monitoring functionality while the computation of relationships is delegated to the system and automated knowledge processes that reduce operator workload.

BeAware (Baumgartner et al. 2010) is an ontology-driven framework aimed at increasing a user’s SA in traffic emergencies. A domain-independent SA ontology (Matheus et al., 2005) is extended by incorporating spatio-temporal primitive relations between observed real-world objects. Moreover, ontology is made an integral part of BeAware throughout its architecture, i.e. it is used for preserving information, for communicating situations to operators and domain experts, and for knowledge representations that may be used in situation assessment algorithms.

AKTiveSA (Smart et al., 2005), aims to explore knowledge-based approaches to information fusion and enhanced situation awareness in military operational contexts specifically humanitarian assistance and disaster relief. To improve SA, AKTiveSA uses domain ontologies that enhance information exchange and inter-operability between diverse agencies and user communities e.g. Non-Government Organizations (NGOs), United Nations (UN) agencies, coalition forces, government departments, etc. The idea

of semantic filters is used to provide filtered views of the situation picture to support task relevant information processing. Knowledge monitors actively watch the situation for incidents that affect current plans or problem solving goals by making use of semantic queries that execute as background processes. The monitors continuously watch the entirety of the information space and update users about relevant changes.

Liu & Fang (2006) developed task ontology to support modelling of activities in emergency response to debris-flow. Little and Rogova (2005) used ontology as a knowledge base for sharing and extracting information. They used ontology to provide a contextual understanding of the post disaster environment by supporting situation awareness of different users. Wenjun et al. (2005) uses ontologies for semantic annotation of emergency events to match the current emergency situations with past ones. Hoogendoorn et al. (2005) used ontology to formally specify, analyse, and compare disaster plans.

All of the ontology based systems to improve SA discussed above focus on individual SA. However, this thesis extends the use of ontologies for automatic SA assessment to support SA, SSA, and TSA of emergency managers. One of the most important reasons to use ontology for SA modelling can be automatic assessment of a situation. Ontology is machine readable so a system that supports ontology modelled situations automatically understands changes in the situation by integrating incoming information on the fly. In addition, the system can run on an inference engine to compare possible risky evolutions of a situation. Therefore, the whole process of situation assessment, which results in SA, can, in principle, be automated to support all levels of human SA including shared and team situation awareness.

## **2.8 Summary and Conclusions**

Emergency management is the planning for and the execution of all emergency functions necessary to mitigate, get ready for, respond to and recover from emergencies and disasters. The mass evacuation of an area is needed when a natural or technological hazard threatens and risks the safety of those within the area. Mass evacuation can also be needed following the impact of a hazard, which has subsequently made the area unliveable. A timely evacuation decision and successful in time evacuation of people from an area at risk can save many human lives. Making a right and timely evacuation decision is based on the correct interpretation of incoming situation information.

This chapter presents an overview of the current literature on situation awareness and its relationship to the design and use of emergency management systems. It synthesizes various concepts related to emergency management and discusses the factors that influence decision making in emergency situations. The emphasis is on systems for mass evacuation but the concepts and outcomes transfer across the whole spectrum of the use of information systems for decision support in emergency responses.

The literature reveals broad agreement on the distinguishing features of systems that support emergency response and the dynamic, stressful and time limited environment in which managers have to make decisions. Researchers also concur on the importance of the role of situation awareness (SA) in decision making but there is no comprehensive understanding of the way in which shared and team situation awareness operate in emergency teams. This is apparent both in the range of terms and models used to describe SA and in the focus on system designs that emphasise only individual SA. More work is needed on the cognitive aspects of shared awareness. Endsley's seminal three-level model of SA offers a good basis for such studies.

The extension of systems design to target the enhancement of shared and team awareness is essential for the future development of emergency management information systems. An encouraging theme emerging in several research groups is the application of ontologies to systems design. Coupled with semantic web technologies, ontological design offers several advantages, not the least of which is the prospect of applying the SA information generated in an emergency to inference projections of future situation states.

To date much of the research on situation awareness in emergency management systems has concentrated on individual situation awareness. More evaluation studies are needed to determine which investigative concepts and directions are likely to progress beyond the exemplar stage. Similarly, it would be fruitful to collect data from using simulation experiments similar to real life incidents to assess the value of the applied models.

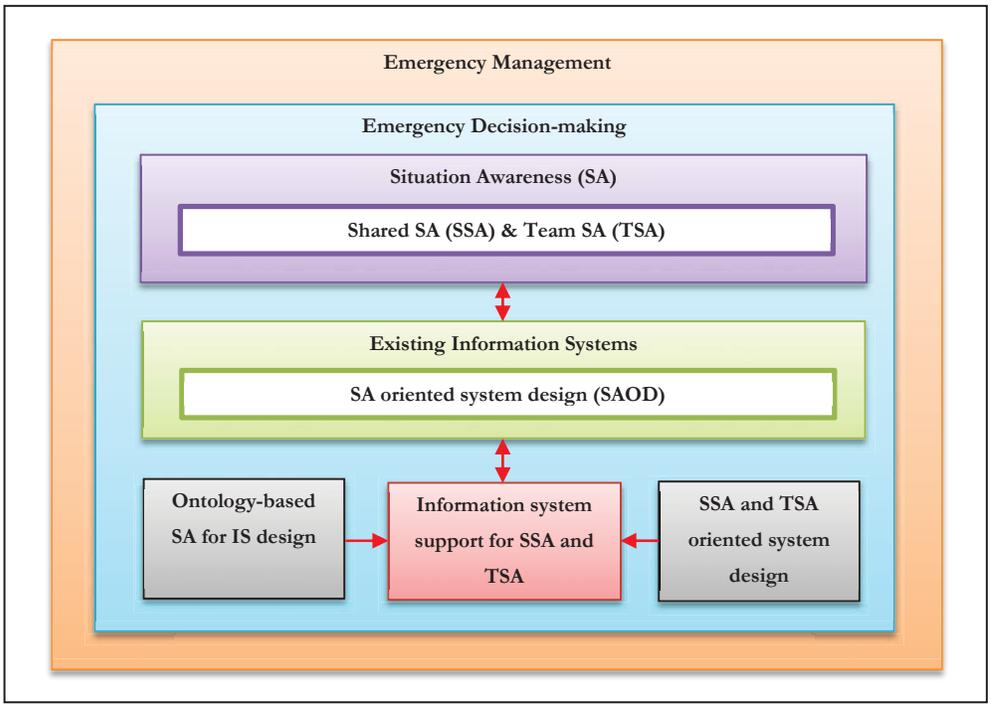


Figure 2.8 Summary of literature review and theoretical framework

# Chapter 3

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## RESEARCH METHODOLOGY

### 3.1 Introduction

This chapter provides an overall research design and the methodological overview of the study in hand. It starts with discussing the philosophical grounding of the Design Science Research (DSR) and then it explains the rationale of choosing the DSR. The chapter then discusses the cycles and phases of the DSR in detail. While explaining the phases, the chapter summarises the identification of problems and opportunities in an emergency decision making environment with special reference to mass evacuation, suggested solutions, design, development and evaluation of the artefacts.

### 3.2 The Philosophical Grounding of Design Science Research

An information system, within an organization supports the processes and functions of the organization to improve its effectiveness and efficiency. Thus, the usefulness of the information system is dependent on the organization's characteristics e.g., its work structure, its human resources and most importantly, the design and development of the information system (Vaishnavi & Kuechler, 2008). Therefore, the information system researchers are working to generate the knowledge that improves the design, development and management of the systems (Zmud, 1997).

Such knowledge is acquired via two complementary but distinct paradigms, *behavioural sciences*, and *design sciences* (Hevner et al., 2004; March & Smith, 1995). Behavioural science originates from the natural science paradigm and seeks the truth. It involves hypothesis generation, data collection, and either approval or disapproval of the hypothesis. As a result a theory develops. Such theories help researchers and practitioners to understand the interactions between humans, technology and organizations. This ultimately affects the design decisions and results in better design, development and management of information systems.

In contrast, design science is a problem solving paradigm whose goal is to produce an artefact, by using analysis, design, implementation and evaluation. Working with the technology, going through the design and development of artefact and understanding

the issues with the usage of artefact, is at the core of this research paradigm. The knowledge generated by this research informs us how an artefact can be improved and how it is better than the existing solutions. Knowledge created as a result of DSR can be in the following forms (March & Smith 1995):

- Constructs (vocabulary and symbols)
- Models (abstractions and representations)
- Methods (algorithms and practices)
- Instantiations (implemented and prototype systems)
- Better design theories

DSR in IS design process, provides solutions to what are considered to be the “wicked” problems (Brooks 1987; Rittel & Webber 1984). Cases with such problems have the following characteristics:

- Ill-defined environments; where user requirements are unclear and unstable
- Complex problems, i.e. problems with many intermingling sub-problems
- Design processes flexible to changes
- Effective solution depends upon the human cognitive abilities, e.g. intelligence or creativity
- Effective solution depends upon the human social abilities (e.g., teamwork)

All of the above problems are evident in the design of the information system to be used for decision making and planning in emergency situations. Therefore, current study uses the DSR approach to achieve its research objectives.

In philosophy, ontology is the study about the nature of being, existence, or reality (Gruber, 1993). Whereas, epistemology is the study that explores the nature of knowledge, e.g. what is knowledge, how is it acquired, how we know what we know, how much can be known etc. Moreover, axiology is the study of values e.g., what values a certain group of people hold. The ontological and epistemological research approaches, which are implicit in natural and social science research, have been described in a number of studies (Bunge, 1984; Guba & Lincoln, 1994). Whereas, Gregg et al. (2001) added the design science research approach to the existing positivist and interpretive research approaches (Vaishnavi & Kuechler, 2008). The philosophical perspective of the design science researcher changes as research progresses through the

phases of DSR. In information system prospective, when a design science researcher identifies a problem in a system, he/she creates an IS (reality) assuming some hypothesis depending on the predictions (theory), to solve the problem. The researcher then reflectively becomes a positivist observer, recording the behaviour of the system, and comparing it to the predictions (theory) set out during the initial phases. The analysed observations become the basis for the new theories and a new research cycle begins.

### **3.3 Rationale for Choosing the Design Science Research**

Design science research helps the researchers to understand the interactions of the human, the information system and the technology. Moreover, it has the potential to provide deep understanding into the phenomenon including the design, development, and management of the information system. This study intends to answer the questions: What are the information requirements of emergency managers to develop Situation Awareness (SA), Shared Situation Awareness (SSA), and Team Situation Awareness (TSA) during a mass evacuation operation? How can ontology be used to support SA, SSA, and TSA? Whether SA, SSA, and TSA oriented system design of SAVER can improve SA, SSA and TSA of emergency managers during mass evacuation operations?

All these research questions justify the use of an approach that allows some features of interpretive study, which is needed to understand the requirements of the emergency managers. For example, the approach provides the design and development of an artefact using ontologies to see how an ontology-based system can be developed to support SA, SSA and TSA. In addition, it allows the evaluation of the artefacts that may have helped to improve the SA, SSA and TSA of emergency managers. All these features are present in a DSR approach.

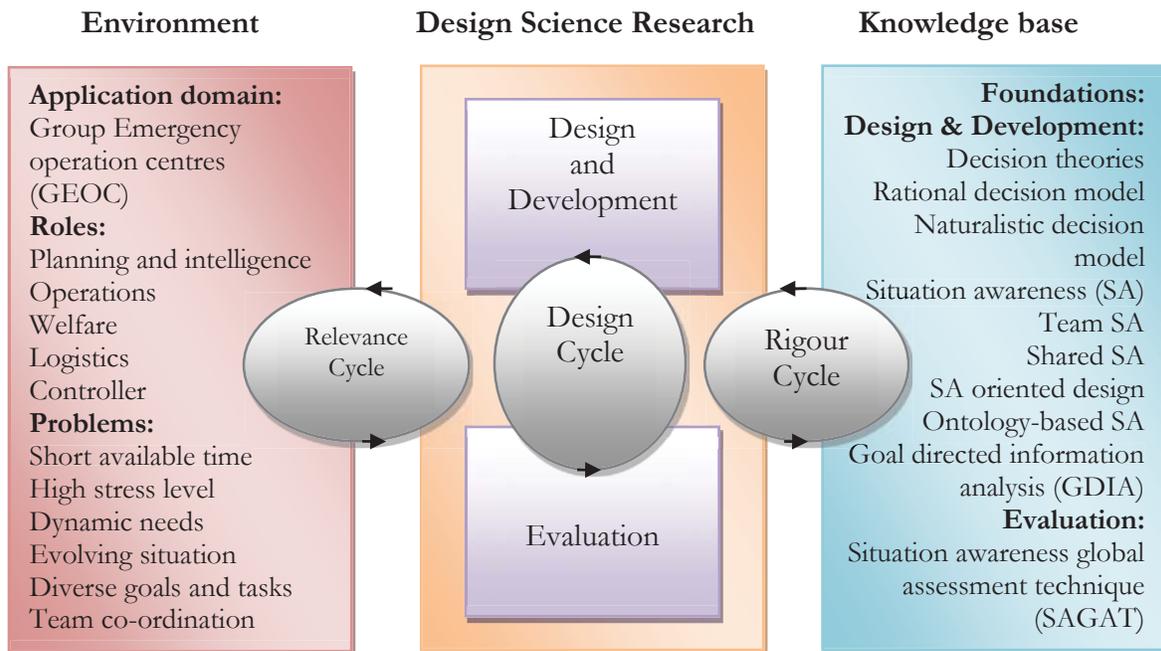
Since the research questions focus on the complexity of human sense making of an emergency situation, the tasks and requirements (physical and cognitive) are dynamic due to the evolving situation which falls under the category of “wicked” problems as discussed above in section 3.2. Consequently, DSR becomes an ideal approach to meet the challenges of such complicated problems.

Moreover, this study uses people’s interpretations to understand their information requirements and the steps involved in comprehending a situation. Moreover, to keep the study legitimate and clear, the method used for the requirements gathering is discussed in detail. Therefore, the requirement elicitation part of this study can be

categorised as interpretive epistemology within a DSR methodology. Since, the research question about the user requirements is open ended and non-directional, a mix of qualitative and quantitative approaches is used.

### 3.4 Design Science Research Cycles

Design Science Research goes beyond the idea of innovative design. In this study, DSR results in clear contributions to the knowledge base and takes several forms including constructs, models, methods and instantiations (March & Smith 1995). However, the important and crucial understanding of emergency management is achieved by recognizing the existence of three DSR cycles in the project as shown in Figure. 3.1.



**Figure 3.1 Design Science Research Cycles (inspired by Hevner, 2007)**

#### 3.4.1 The relevance cycle

DSR is driven by the need to improve the system by proposing novel artefacts or the methods for developing these artefacts (Simon, 1996). DSR usually starts with the identification and representation of opportunities and problems in an actual application domain. Therefore, in this study, the relevance cycle initiates DSR with an application context that helps in describing the objectives of the research (e.g., the opportunity/problem to be addressed) and outlines the acceptance criteria for the final evaluation of the proposed artefact or research results.

Decisions are the most important part of emergency management activities. To make correct and timely decisions, a certain level of SA, SSA and TSA is required by emergency managers. Current study is focused on supporting and improving the SA, SSA and TSA of emergency managers using a computer based system, so that their decision making and task performance capability can be improved. The design and development of such a computer based system is a vital part of this research.

Evaluation of the artefacts helps in answering questions like; does the artefact solve the problem or improve the environment and how can this be measured? (Hevner et al., 2004). The field study of the artefact can be done using various empirical methods and techniques similar to theory testing (March and Smith 1995), action research (Cole et al. 2005; Jarvinen 2007), controlled experiments, simulation or scenarios. The results of the field testing determine whether any further iterations of the relevance cycle are needed in this DSR project or not (Vaishnavi & Kuechler, 2008).

Evaluation of the artefact reports problems in the functionality, performance or usability that may bound the usefulness of the artefact in its application domain. Field testing may also show that the identified requirements were incorrect or incomplete so that the proposed artefact is satisfying the requirements but is still inadequate to solve the problem. Consequently, an additional iteration of the relevance cycle may be required while considering the received feedback from field testing.

An evaluation criterion for the proposed design is based on whether the design activities successfully used the opportunities arising from the application of semantic web technologies or not. The evaluation must make sure that the requirements gathered are comprehensive enough to develop the required levels of SA, SSA and TSA during a mass evacuation operation. In addition, the tests have to check if the proposed system improves the SA, SSA and TSA of the emergency manager during the mass evacuation operations, which is the main aim of the study.

### **3.4.2 The rigour cycle**

A huge knowledge base of scientific theories and engineering methods provide the basis for rigorous DSR. The knowledge base also contains two additional types of knowledge in that application domain (Vaishnavi & Keuchler, 2008):

- The experiences and expertise that is the state of the art

- The existing artefacts and processes to develop them

The rigor cycle, bases the research project on the past knowledge to ensure its novelty. The research thoroughly references the existing knowledge base to guarantee that the new design produced is a research contribution and not a replica of existing artefacts or the methods to develop them. While applying the existing knowledge base theories to the research project, care is taken to make sure that the sources and types of rigor are appropriate for the DSR project in hand; this will also help in providing novelty to the new design.

The theories used in this research include decision theories (Klein, 1999), which suggest situation awareness (SA) as the most important factor that is responsible for rapid and effective decision making in emergency situations. In addition, since a team of decision makers is involved in large scale emergencies like mass evacuation as a result of tsunami or volcanic eruption threat to a large city, therefore apart from an individual's SA, having an acceptable level of shared and team SA (SSA and TSA) is also important.

Moreover, an SA oriented system design (Endsley et al., , 2003a) can be used to design and develop the system to support SA and the resultant decision making of emergency managers. In the current study this approach is used for designing and developing an IS for supporting the SA, SSA and TSA of an individual and a team during a mass evacuation operation. To capture the dynamic information requirements needed to develop and maintain SA, SSA and TSA, a cognitive tasks analysis technique, Goal Directed Information Analysis (GDIA) (Prasanna et al., 2009) is used. GDIA has been used to acquire the information requirements of the different roles of emergency managers in a fire emergency. For the current study, this technique is extended for tsunami scenarios. Information requirements for developing SSA and TSA are also captured.

It may not be appropriate or even feasible to base all design decisions on grounded behavioural or mathematical theories as such theories may as yet be undiscovered or incomplete and the research activities of design and evaluation of the artefact may advance the development and study of such theories. Current study is also expected to reduce the differences found in various definitions of SA, TSA, and SSA by providing a framework for defining them. Rigor in the DSR depends on the researcher's selection

and the application of the appropriate theories and methods for the design, development, and evaluation of the artefact.

In the current study, the widely accepted technique - Situation Awareness Global Assessment technique (SAGAT) (Endsley, 2000) is used to measure SA and evaluate the artefact. This technique is extended to measure SSA and TSA. In addition, inspiration for a creative design activity can be drawn from the application environment, existing artefacts and theories, to develop effective problem solving approaches (Iivari 2007). Results, which can be in the form of extension to the existing theories, new original theories or evaluation and feedback related to the artefact, are added to the existing knowledge base. It is apparent that this DSR project makes a persuasive case for its rigorous base and contributions to the knowledge base of an emergency management information system.

### **3.4.3 The design cycle**

The design cycle is at the core of any DSR project. It iterates between the design of an artefact, its development and its evaluation to refine the design further. Simon (1996) explains this cycle as developing design alternatives and evaluating them against requirements until an acceptable design is achieved which fulfils the requirements. As described in the above sections, the relevance cycle provides the requirements as an input to the project and the design, development and evaluation methods and theories are drawn from the rigor cycle (Vaishnavi & Kuechler, 2008). However, the design cycle is where the actual DSR is done. During the design cycle, there must be a balance between the efforts spent on developing and evaluating the artefact and both activities must be credibly built on relevance and rigour. Having a strong grounded argument for the development of an artefact is not enough if its evaluation is not properly done (Iivari, 2007).

In this study, the focus is on a balance between the development and evaluation of the artefact. The research described here provides the creativity required by the DSR at every step. For example, from requirements elicitation to design and development and evaluation at the end, most appropriate methods and techniques (as discussed in the previous section) are chosen from the relevant literature and are used creatively to meet the needs of the project in hand. Moreover, ontology based SA is suggested to meet the

requirements of the dynamic information integration and situation modelling to support SA, SSA and TSA, which is a major innovation in itself.

### 3.5 The Design Science Research Methodology (DSRM)

In this section, the general design science research methodology (DSRM) is described with reference to the research in hand. Peffers et al. (2008) propose a DSRM for information systems. This work provides a commonly accepted framework for carrying out a successful DSR project in an information system, which avoids more ad hoc approaches (Peffers et al., 2008; Vaishnavi and Kuechler, 2008; Hevner and Chatterjee, 2010). Figure 3.2 shows, a typical framework for design science research.

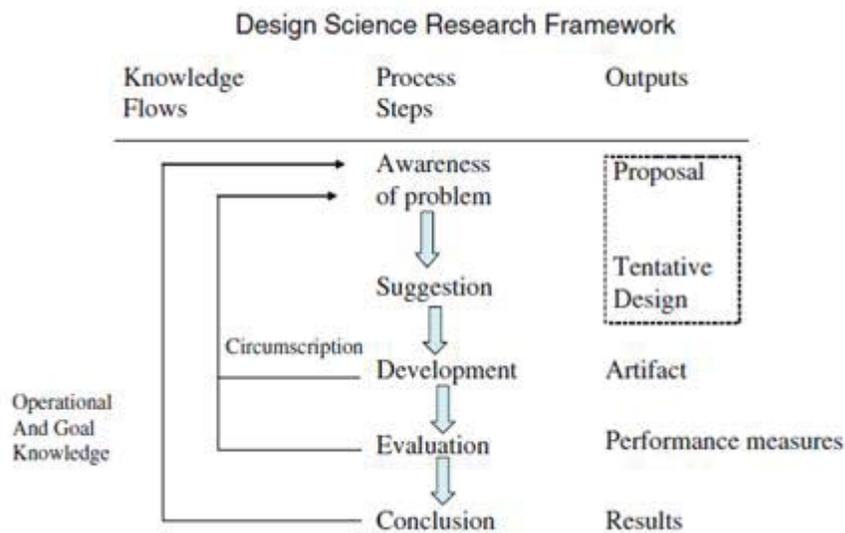


Figure 3.2 General design cycle (adopted from Vaishnavi and Kuechler (2008))

In the current study, design begins with the awareness of the problem. From this stage, the problem is identified and defined. The next stage suggests, preliminary solutions that are abductively drawn from existing theories and practices rooted with the emergency decision making domain. In the next stage, design decisions are made, and a prototype solution based on information requirements is developed. After completion, the prototype is evaluated in the final stage according to the stated objectives and criteria. These stages are now described below in detail.

#### 3.5.1 Awareness of problem/opportunity

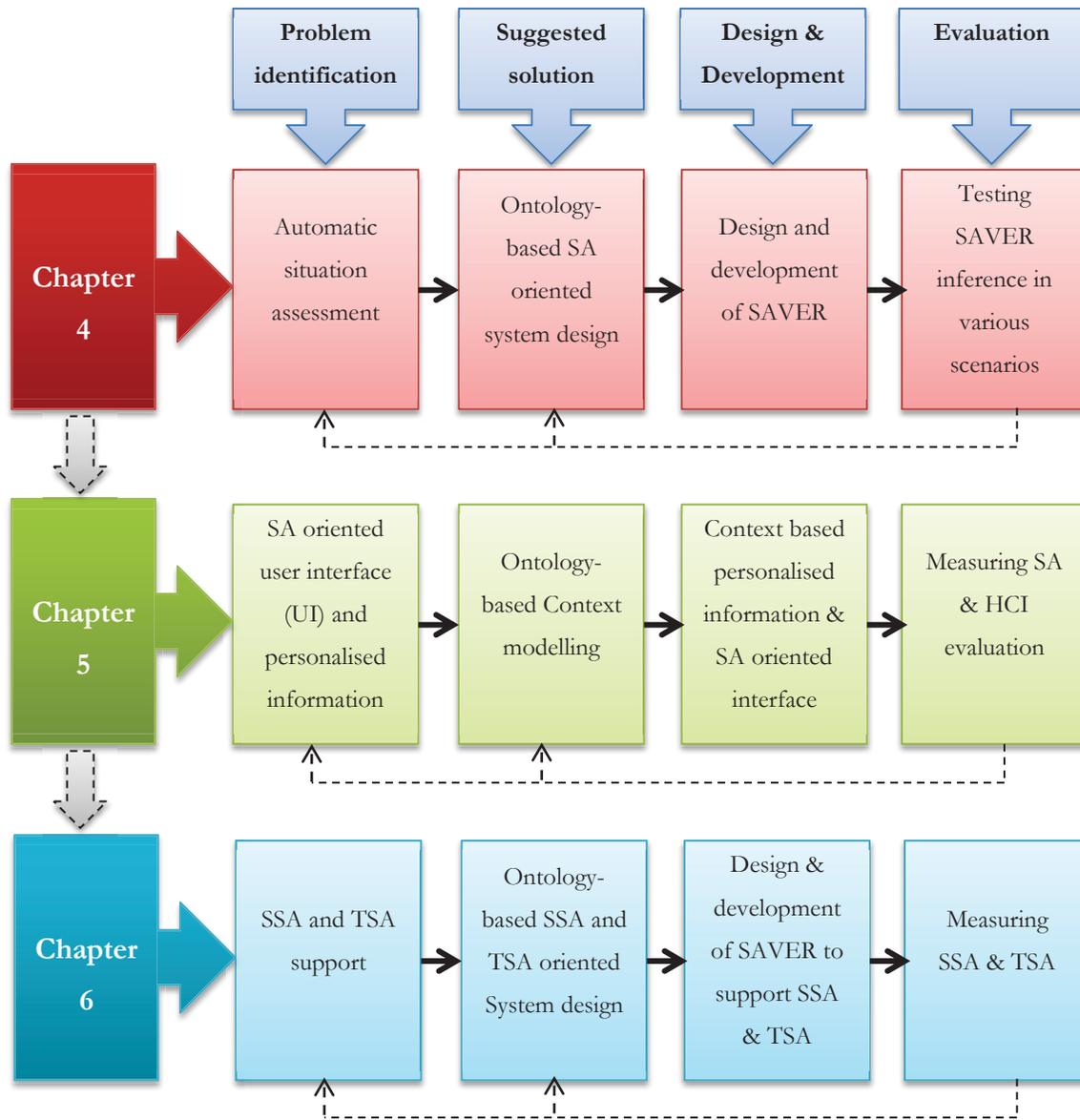
This step is also called “Problem identification” (Hevner and Chatterjee, 2010) or “Opportunity identification” referring to the problem of improving the existing system or environment. In this step, the research problem or opportunity is identified and

described. An awareness of the problem or opportunity can come from various sources; for example, from an existing problem that was previously ignored or from a new problem generated by new developments. Similarly, the opportunities can appear with the development of new technologies to improve the performance of the staff or processes used in an organization. The output of this phase is a proposal for a new research effort to solve the problem or realise the opportunity.

In the current study, the awareness of the problem came from the national level exercises (namely; Ruaumoko and Tangaroa) performed in New Zealand to test the nationwide response of organizations to large scale emergencies like volcanic eruption or tsunami risk. During the exercises, it was noticed that huge amounts of time were consumed in communicating about the situation information (sitreps) and co-ordinating activities and in dealing with information overload (Ruaumoko final report, 2010; Tangaroa final report, 2011; Javed et al., 2011b). Therefore, a computer based information system is needed, which can help emergency managers in developing and maintaining SA and the overall situation picture. Further, such a system is also needed to support co-ordination of activities among a team.

To design and develop an artefact that can effectively address the problem definition or opportunity, it may be helpful to break the overall problem into smaller simpler and specific problems so that the solution can capture all aspects of the problem and nothing is left out (Hevner and Chatterjee, 2010). Therefore, the problem related to the design and development of the prototype system to support SA, SSA and TSA of emergency managers is decomposed into three sub-problems and discussed individually in the upcoming chapters. However, the summary of the problem division is given below and shown in Figure 3.3:

- System design using an ontology based SA modelling (details in chapter 4)
- System design supporting individual SA (details in chapter 5)
- System design supporting shared SA and team SA (details in chapter 6)



**Figure 3.3 Dividing the problem in DSRM according to the thesis chapters**

With the recent spread of semantic web systems, an ontology based SA modelling can be considered as an opportunity, which can lead to many advantages. Moreover, it can also be a solution to some of the problems of system design and development in the emergency management domain. Detail of all these applications and advantages of ontology based SA modelling are left to Chapter 4 to avoid repetition.

### 3.5.2 Suggested solution to the problem

This activity is also called “*Define the objectives for a solution*” (Hevner & Chatterjee, 2010). In this phase, a proposed solution is explained with all of its objectives, benefits, and the

justification for its design and development. This motivates the researcher and the stakeholders to pursue the solution, to accept the results and to understand the relationship between the problem and the proposed solution (Hevner & Chatterjee, 2010). The Suggestion phase follows immediately after the Proposal. In any formal proposal for design science research, a proposed design and the likely performance of a prototype based on that design are of utmost importance. After consideration of a problem, if a proposed design does not appear to be promising enough to the researcher, the proposed idea will be modified, replaced by another one or simply dropped.

Suggestion is a creative step wherein the working of a new system is projected based on a novel configuration of existing or new features. Moreover, in this step, the objective of the solution in relation to the problem definition and knowledge of what is conceivable and practical is described. The objectives can be quantitative, e.g., using terms to describe how a proposed solution would be better than the existing ones, or qualitative, e.g. a description of how a new artefact is anticipated to provide a solution to the problem. The objectives should be justified logically from the problem specification. Resources required for this include knowledge of the proposed solution and current solutions, if any, and their efficacy.

In this research, a computer based information system is proposed as a solution to the problems discussed in the previous section. The system can support individual Situation Awareness (SA), Shared Situation Awareness (SSA), and Team Situation Awareness (TSA). Such a system can help emergency managers to make accurate decisions and perform tasks effectively and efficiently during emergency situations e.g., a tsunami threat to a large city. It is hypothesised that proactive sharing of information by a computer based information system can update human a decision maker's SA, as any other team member does. In addition, making the suggestions that assist the comprehension of the prevailing situation and information needed to complete relevant tasks can reduce the time and effort needed to develop SA, SSA and TSA.

A further objective of system design using ontology based SA modelling is to see how ontology can be used to model SA. Existing ontology based SA modelling techniques, e.g. by Matheus et al., (2004) are extended to see whether SA modelling requirements of the current study can be fulfilled using ontology or not. Moreover, Matheus et al., (2004)

only provided a top level situation ontology, which needs extension to a real scenario. More detail of the suggested solution along with the developed ontologies is provided in Chapter 4. System design supporting individual SA is achieved by an SA oriented system design that is a user centred design approach (Endsley et al., 2003a). In addition, personalised information according to the context should be presented to the emergency managers to avoid information overload. Further details of suggested user interface and contextual information presentation are covered in chapter 5. System design supporting shared SA and team SA depends on the correct identification of SSA and TSA requirements. Therefore, the SSA and TSA requirements should guide the design of a system, supporting SSA and TSA. Details of SSA and TSA requirements and the suggested solution to SSA and TSA systems design are described in chapter 6.

### **3.5.3 Design and development**

As the name shows, this activity is concerned with the design and development of the proposed artefact. The artefacts are in the form of a model, method and a prototype (Hevner et al. 2004). Theoretically, a DSR artefact can be any designed entity in which a research contribution is embedded in the design. This activity includes designing the artefact architecture to provide the required functionality and to fulfil the desired objectives listed in the previous step and then developing the real artefact (Hevner and Chatterjee, 2010).

Designing a successful artefact requires a lot of innovative exertion. Apart from using the existing theories and processes, innovation has to be applied in this step to make the artefact unique and useful among the existing solutions. Therefore, it is the most challenging activity in the DSRM. The completed design is transformed into the real artefact that embodies the features that solve the identified problem.

Development methods again vary, depending on the artefact to be constructed and the design decisions to be made. For example, an algorithm may require construction of a formal proof whereas an expert system expressing novel features in certain areas of interest may require software or tool development, which is the case in the current research. The implementation itself can be very ordinary and does not need novelty beyond the normal development practice for the similar artefact thus the novelty is mainly in the design, not the construction of the artefact (Hevner and Chatterjee, 2010; Vaisnavi and Kuechler, 2008). Current research has the clear objective to design a

computer based system to improve SA, SSA and TSA of emergency managers in an emergency situation. Relevant theories, methods, and techniques are creatively applied in design and development. These design and development decisions are discussed below.

### ***3.5.3.1 Design decisions***

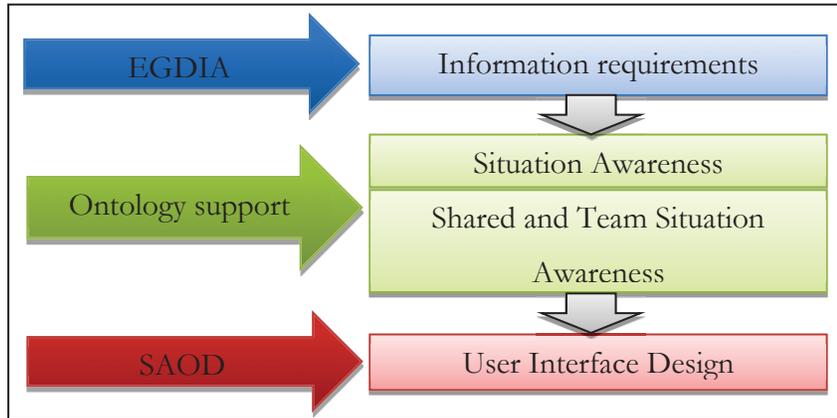
To provide computer based SA support, situation information needs to be modelled in detail. However, the first step in this regard would be to identify the information required to develop and maintain SA in a particular scenario. As discussed earlier, along with the physical tasks, many cognitive processes are also involved in SA development; a cognitive task analysis technique is needed to identify these information needs. Extended Goal Directed Information Analysis (EGDIA) is used for information elicitation of various user groups. Details can be found in chapter 4. The second step would be to provide the information needed for developing and maintaining a required level of SA by using ontologies for:

- Automatic information integration
- Modelling situation evolution
- Classifying information according to the different levels of SA

Moreover, ontologies can also solve the problem of the dynamic information requirements of emergency managers in evolving emergency situations, as ontologies are easy to update dynamically and are very flexible to model situation (Matheus et al., 2004) and context (Chen, 2004) information. In addition, ontologies, when used with a reasoner, also provide inference capability to show how a situation may evolve. More details of ontology based design are discussed in Chapter 4.

The system to support SA is devised by following the SA oriented design process (Bolstad et al., 2006; Endsley, 1995b). This design process suggests developing user interfaces, which provide goal and task oriented information. This design method also promises that providing the higher level of SA information to the user, improves his/her SA instead of simply providing the raw data which needs further processing. Moreover, the context information is used to provide the personalised and specific information to emergency managers during a mass evacuation operation to minimise the problem of information overload. Details of these design decisions are covered in chapter 5.

To deal with the problem of system design for supporting SSA and TSA, SA oriented design is extended to provide higher levels of Shared and Team Situation Awareness (SSA and TSA). Hence, information requirements needed for SSA and TSA are identified by keeping the individual SA requirements and various definitions of SSA and TSA in view. Further details of system design to support SSA and TSA are provided in chapter 6. The prototype designed to address these issue is dubbed Situation Aware Vigilant Emergency Reasoner (SAVER) and its overall design steps are shown below in Figure 3.4.



**Figure 3.4 Steps of design**

### ***3.5.3.2 Development decisions for ontology based SAVER***

Web Ontology Language (OWL<sup>6</sup>) is used for developing the ontologies needed for the implementation of SAVER. World Wide Web (W3C) endorses OWL for authoring ontologies. OWL is characterised by the formal semantics and uses serialisation, based on Resource Description framework (RDF<sup>7</sup>) and Extensible Mark-up Language (XML). The reason for choosing OWL is that it is a modelling language that can facilitate greater machine interpretability of Web content rather than that supported by XML, RDF and RDF Schema (RDF-S). It is because OWL provides an additional vocabulary along with the formal semantics.

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<sup>6</sup> <http://www.w3.org/TR/owl-features/>

<sup>7</sup> <http://www.w3.org/RDF/>

Semantic Web Rule Language (SWRL)<sup>8</sup> is used to state the rules for defining relationships between various domain concepts and applying restrictions to these relationships. SWRL is a semantic web rules-language, combining OWL with those of the Rule Mark-up Language (unary/binary data-log). SWRL has the full power of OWL DL (description logics). The domain and application ontologies were developed using Protégé 4.0.2<sup>9</sup> and the programming interface to ontologies were developed in Java using the OWL application-programming interface (API)<sup>10</sup> and Jena<sup>11</sup> API. OWL API is an open source reference implementation for creating, manipulating, and serialising OWL ontologies and is available under the Lesser General Public license (LGPL)<sup>12</sup>. Jena is a Java framework for building semantic web applications. Jena provides a collection of tools and Java libraries to develop semantic web and linked-data applications, tools and servers. Fact Plus Plus (Fact++)<sup>13</sup> is used as a reasoner for ontology validity and inference. A reasoner is a key component for working with OWL ontologies. Virtually all querying of OWL ontology is done using a reasoner. This is because knowledge in ontology might not be explicit and a reasoner is required to deduce implicit knowledge so that the correct query results are obtained. The OWL API includes various interfaces for accessing OWL reasoners.

The front end/user interface was designed using the Vaadin<sup>14</sup> application framework. Vaadin is a web application framework for Rich Internet Applications (RIA). Unlike JavaScript libraries and browser-plugin based solutions, it features robust server-side architecture. Therefore, the largest part of the application logic runs securely on the server. Google Web Toolkit (GWT)<sup>15</sup> is used on the browser side to ensure a rich and fluent user experience. The main reason for choosing Vaadin is its easy programming model. Moreover, Vaadin is a robust architecture for rapid application development. The component based architecture together with statically typed Java language and data binding features helps in building applications that are easily modularised and refactored

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<sup>8</sup> <http://www.w3.org/Submission/SWRL/>

<sup>9</sup> <http://protege.stanford.edu/>

<sup>10</sup> <http://owlapi.sourceforge.net/>

<sup>11</sup> <http://incubator.apache.org/jena/>

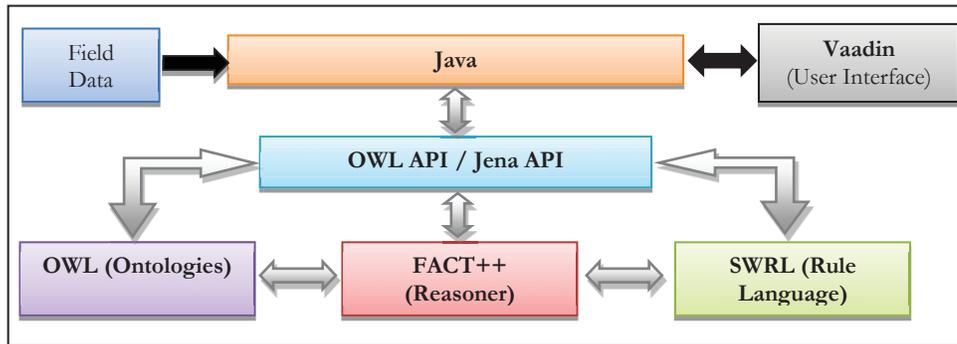
<sup>12</sup> <http://www.gnu.org/licenses/lgpl.html>

<sup>13</sup> <http://owl.man.ac.uk/factplusplus/>

<sup>14</sup> <https://vaadin.com/home>

<sup>15</sup> <http://code.google.com/webtoolkit/>

as needed. The integrated development environment (IDE) and support including visual designing tool helps to build a web user interface extremely fast. The system architecture showing components of SAVER is shown in Figure 3.5 below:



**Figure 3.5 System architecture of SAVER**

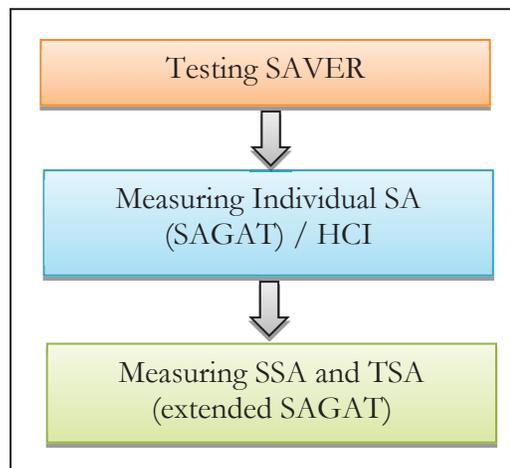
### 3.5.4 Evaluation

Once developed, the artefact must be evaluated against the problem definition that is implicit and frequently made explicit in the section 3.4.1 “Awareness of problem” and the objectives set in section 3.4.2 under the heading “Suggested solution to the problem”. Deviations from expectations, both quantitative and qualitative, are carefully noted and must be justified. The evaluation phase contains a sub-phase in which hypotheses are prepared about the behaviour of the artefact based on objectives set in suggested solution and problem identification phases. For example, in current research, it is hypothesised that SA oriented design will support SA of emergency managers and the proactive sharing of information according to SSA and TSA requirements will improve SSA and TSA of emergency managers. Additionally, in the other sub-phase, an analysis to either confirm or contradict an hypothesis is provided. In conventional research, after discussing the considerations for future work, the research effort is finished but for the design science researcher, by contrast, it is rare that a hypothesis is completely borne out after the first cycle of DSR. Instead, the evaluation phase results and knowledge gained during the design and development phase is fed back to Suggestion (cf. see the arrows going back in Figure 3.2) for another cycle. This concept has been observed by philosophers of science in many areas (Lakatos, 1978); and working from it, Newell suggests that theories should be treated like doctoral students who are corrected when they make a mistake and they go on to be ever more valuable and creative (Newell, 1990).

Evaluation of the artefact involves its use in experimentation, simulation, case study, proof or any other suitable and related activity. Performance of the artefact in the field is observed and measured to see how well the artefact supports a solution to the problem. This phase requires knowledge of relevant metrics and analysis techniques. Evaluation can be of many types depending on the problem domain and features of the artefact itself. The artefact's functionality and the testing results are compared with the solution objectives from the "Suggestion" phase described above. Evaluation may also include objective quantitative performance measures such as the number of items produced, quantifiable measures of system performance such as response time, availability or increase in productivity against used resources (efficiency), satisfaction surveys or client feedback. Therefore, the evaluation could include any suitable empirical proof or logical evidence. At the end of evaluation, the researcher decides whether it is required to iterate back to the previous steps to improve the effectiveness of the artefact or to leave further improvements for subsequent projects (Hevner & Chatterjee, 2010). The nature of the DSR and application domain may also direct whether iteration is possible or not.

The evaluation of the design in the current study starts with the testing of ontology-based modelling of SA, i.e. to examine if ontology can be used to model a situation. This is done by testing the system for inference capabilities using test cases, which are prepared as scenarios for evaluation to assess if the inference and suggestions made by the system are correct and useful. The details of testing process, scenarios, and results are provided in Chapter 4.

The proposed design in this research intends to improve SA, SSA and TSA. Therefore, SA, SSA and TSA are measured to evaluate the design and prototype. A widely accepted technique, Situation Awareness Goal Assessment Technique (SAGAT) (Endsley, 1995a), is used to measure individual SA. Since user interface design plays an important role in improving SA, it is also evaluated using human computer interaction (HCI) matrices (Bailey et al., 2000; Sauro & Kindlund, 2005; Tullis & Albert, 2008). Details of SA measurement and user interface evaluation along with the results are covered in Chapter 5. SSA and TSA are measured in experiments conducted with eight pairs of emergency managers. SAGAT is extended for measuring SSA and TSA. Details of SSA and TSA measurements are described in Chapter 6. Figure 3.6 summarizes the principle of its evaluation process.



**Figure 3.6 Evaluation method**

### 3.5.5 Conclusion

This is the final phase of a particular design science research (DSR) effort. This phase comes once satisfactory results of evaluation have been achieved and no more iteration is planned in the current project. Even if small discrepancies are still present in the behaviour of the artefact but results are good enough to justify the research effort within the scope of that project, research is concluded (Hevner & Chatterjee, 2010; Vaishnavi and Kuechler, 2008). Apart from the results, the experience and learning at every phase of the project is also part of the new knowledge. Abnormal behaviour that is confusing and cannot be explained may well serve as the subject of future research. New knowledge generated is reported and published so that other researchers can make use of it in future DSR.

Results from the evaluation of each design are discussed in the conclusion sections of their respective chapters i.e. 4, 5, and 6. These sections add knowledge and learning from the new design process. In addition to the theory and practices, the impact of the new results and techniques learnt are also discussed in chapter 7. The overall DSRM, adopted for the current study is shown in Figure 3.7 below:

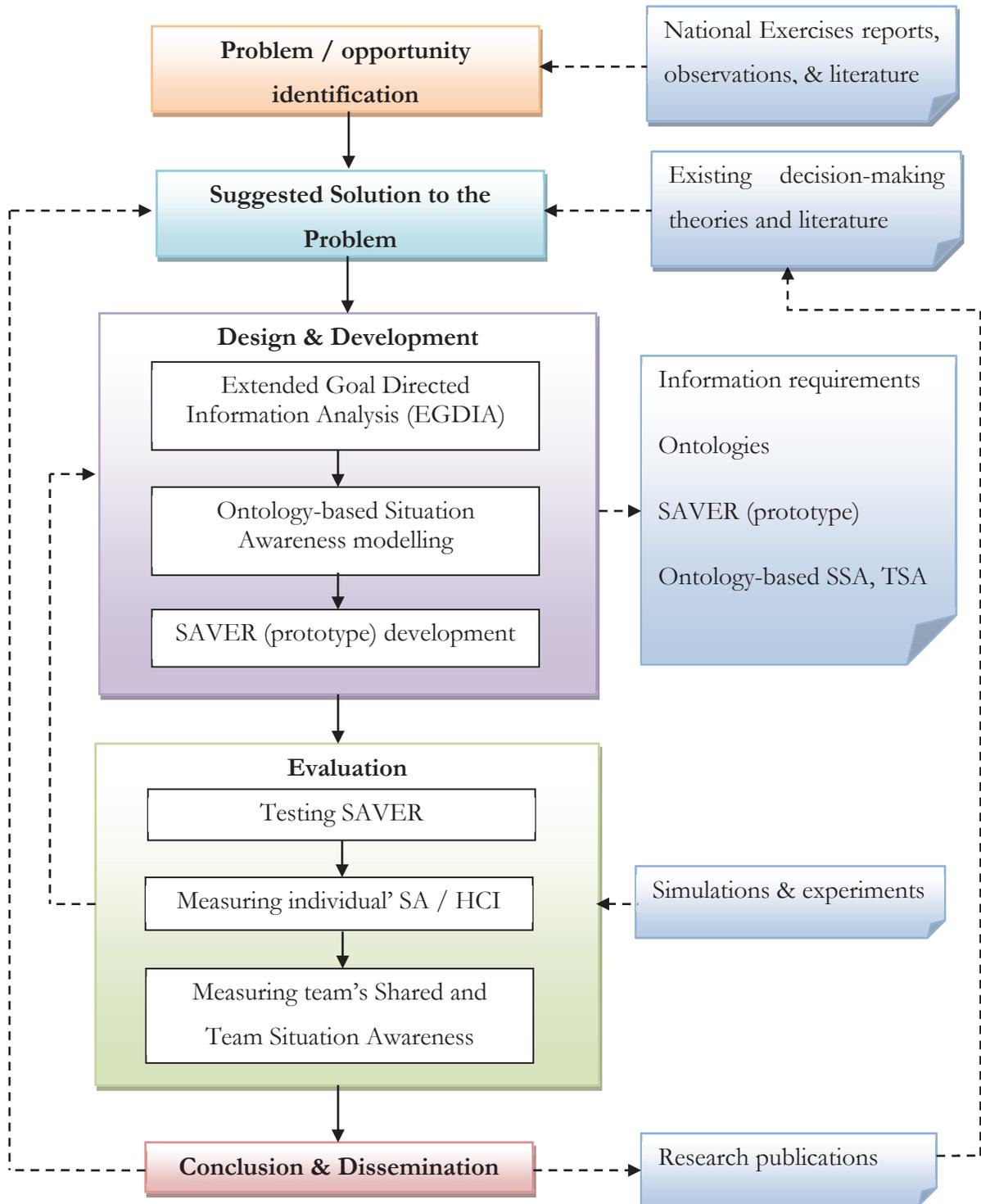


Figure 3.7 Overview of research methodology

# Chapter 4

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## SAVER: SITUATION AWARE VIGILANT EMERGENCY REASONER

### 4.1 Introduction

Decision making is a vital part of emergency management. In every phase of an emergency, decisions are made to control the situation or return it to normal. To make these decisions managers need to integrate different types of information from diverse sources so they can analyse and interpret the material to form an accurate understanding of the situation.

Giving meaning to the incoming information is a complex task as many factors, e.g. attention level, past experience, cultural background, training, intelligence etc. can influence the process. Consequently, different people can generate very different interpretations of the same incoming information.

This research proposes a computer based system to support the information analysis of managers so they can collectively form a more realistic understanding of the emergency and deliver optimal decisions. Semantic web technologies are proposed to model the domain knowledge of the emergency situation and automatic information analysis to set the basis for improved situation awareness.

This chapter first elaborates the problem relating to the requirement of computer based situation awareness (SA) and opportunities arising from having automatic information integration for SA. Moreover, a problem of acquiring the detailed SA requirements is discussed. In the next section, a cognitive tasks analysis technique is suggested for requirements elicitation. In addition to this, the design and development of a computer based system to enhance SA is explained. The next section, explains the design and development of the proposed solution prototype. The chapter then presents the evaluation of the design and prototype for successful situation modelling and accurate and useful information analysis by using four different simulated scenarios. The section on evaluation of the design and prototype is followed by a conclusion section.

## 4.2 Problem Identification

For emergency decision making during a mass evacuation operation, there is a need to receive or acquire the relevant information from diverse sources, integrate this information and present it to decision makers according to their requirements in a readily usable format. Doing all of this work manually takes a lot of time and can result in delayed decisions with potentially serious consequences.

Consequently, a computer based system is required to support human reasoning and the related processes that improve SA. For the successful design of such a system, human cognitive requirements must be considered in addition to the physical task requirements. However, realising these requirements is not an easy job as many cognitive processes are involved in developing and maintaining situation awareness. In addition, an emergency situation is continuously evolving and hence the requirements are dynamic according to the nature and phase of emergency. Realising the requirements in sufficient detail is a challenge. Systems designed based on these requirements must be able to integrate information automatically so that the incoming data can be made readily useable. This information interpretation requires semantic information analysis to understand the meaning of information in the prevailing situation.

A computer based system that is capable of situation analysis requires a situation to be modelled in detail. This means all the important relationships between the concepts related to the domain must be defined. Nevertheless, since emergency situations are dynamic, i.e. continuously evolving, a situation sometimes arises that is not supported by the existing schema and new relations or even new tables in the databases are needed depending upon the situation. Therefore, runtime changes in the schema are needed. These are difficult to manage even using very advanced database management systems. The main problems can be summarised as follows:

1. Acquiring dynamic information needed for developing and maintaining situation awareness
2. Classifying information requirements according to the nature and phase of a mass evacuation operation
3. Automatic integration of information from multiple sources in a semantically coherent and operationally useful manner

4. Providing information at all three levels of SA required for decision making and tasks completion

### **4.3 Suggested Solution to the Problem**

This study suggests a computer based SA system as a solution to the problems mentioned above. A system capable of acquiring the required information from different sources, integrating it and transforming it into a readily usable form, can address the problems identified above. This processed information can be provided to the decision makers according to the requirements of their roles and goals during a mass evacuation operation. Moreover, a system that can interpret the meaning of incoming information and provide advice on all three levels of SA would be highly useful. Hence, the system should first have a capability to identify the relevant information on the perception level of SA according to the role and phase of the emergency situation. The system should then provide information for the comprehension<sup>n</sup> (second) level of SA to explain the significance of the perceived information in the context of the prevailing situation and the user's (emergency manager) goal. To help emergency managers make decisions and perform tasks proactively, the system should also predict the future states of the situation, i.e. deliver level three of SA information.

Detailed SA requirements can be acquired using a technique like Cognitive Task Analysis (CTA). CTA helps researchers to identify what an individual (or team of individuals) needs to do as cognitive processes or actions to achieve his/her goals. Since traditional task analysis techniques fail to identify the cognitive processes associated with an activity (Kirwan & Ainsworth, 1992), CTA becomes an important tool for system designers, where identification of cognitive demands is critical for the system requirements (Stanton et al., 2005; Clark et al., 2008). Several CTA tools are available (Flanagan, 1954; Klein, 1989; Militello & Hutton, 1998; Vicente, 1999; Endsley et al., 2003b) so an appropriate technique must be selected to acquire comprehensive SA requirements.

In this research, to tackle the issue of dynamic situation modelling, ontology based domain modelling is used since ontology based systems can solve the problem of information integration from diverse sources as required in emergency situations (Smart et al., 2005). Other problems that can be addressed by the use of ontology based systems include use of semantic web crawlers for automatic information gathering,

dynamic situation and context modelling. In addition, the problem of dynamic changes in the database schema can also be handled using ontology based systems. Detailed advantages of a semantic web based system are described in the upcoming design section.

## **4.4 Design and Development**

This research focusses on the design of an information system supporting the situation awareness (SA) of emergency managers in mass evacuation operations, specifically in tsunami scenarios. Design and development of a system usually starts with the requirements gathering process.

### **4.4.1 System requirements elicitation**

Successful design and development of a system depends highly on the correct system requirements elicitation as the majority of software problems are attributed to mistakes made at the requirements gathering phase (Jones, 1994). Several authors have identified problems in traditional requirements engineering techniques (Robinson & Elofson, 2004) and proposed alternatives, e.g. soft system method (Checkland, 1999), scenario based approaches (Weidenhaupt et al., 1998), rational unified process (Dardenne et al., 1991).

Since, in emergency situations, the user environment is extremely dynamic and continuously changing, the system must also support dynamic user requirements. General software engineering techniques are not well suited to capture such requirements in detail and with accuracy (Endsley et al., 2003b). Moreover, as described in Chapter 2, User Centred Design (UCD) is capable of capturing the correct information requirements of users by focusing on their needs instead of advising them on what they should use (Jennex, 2007; Endsley et al., 2003b).

#### ***4.4.1.1 Selecting an appropriate cognitive task analysis (CTA) technique***

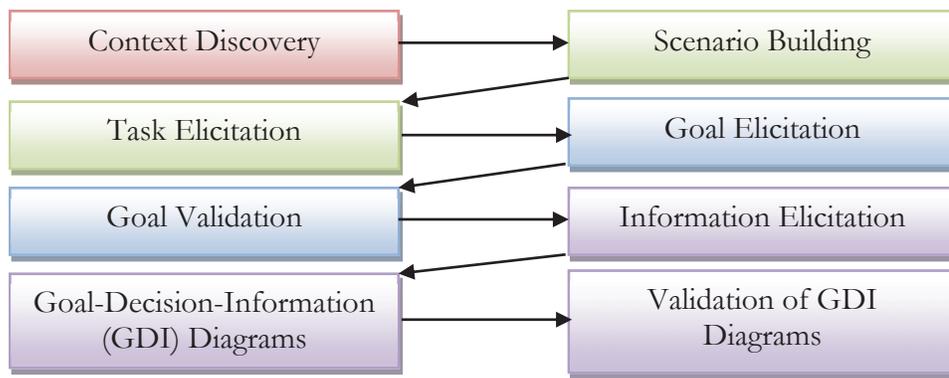
SA is developed and maintained by having up to date information about the situation therefore SA requirements are actually various types of information.

Existing CTA techniques include Goal Directed Tasks Analysis (GDTA) (Endsley et al., 2003b), Critical Decision Method (CDM) (Klien et al., 1989), Cognitive Work Analysis (CWA) (Vicente, 1999), Applied Cognitive Task Analysis (ACTA) (Millitello & Hutton, 1998), Goal Directed Information Analysis (GDIA) (Prasanna et al., 2009). Prasanna et

al. (2009) provide a detailed comparison of ACTA and GDTA. They argue that ACTA is only capable of providing the cognitive requirements relating to a user’s performance whilst GDTA is capable of providing information requirements to make better decisions to achieve a user’s goals. These techniques can be combined to develop the GDIA technique so that complete and comprehensive information requirements can be captured (Prasanna et al., 2009). The requirements gathering process can then start by asking emergency managers about their tasks in a given scenario, the reasons for the specified tasks are queried to understand an emergency manager’s goals and cognitive demands. These queries lead to the information required for carrying out these tasks. GDIA has been successfully used for information gathering in similar complex scenarios, e.g. fire emergencies (Prasanna et al., 2009; Yang et al., 2009), and hence will be used for this research.

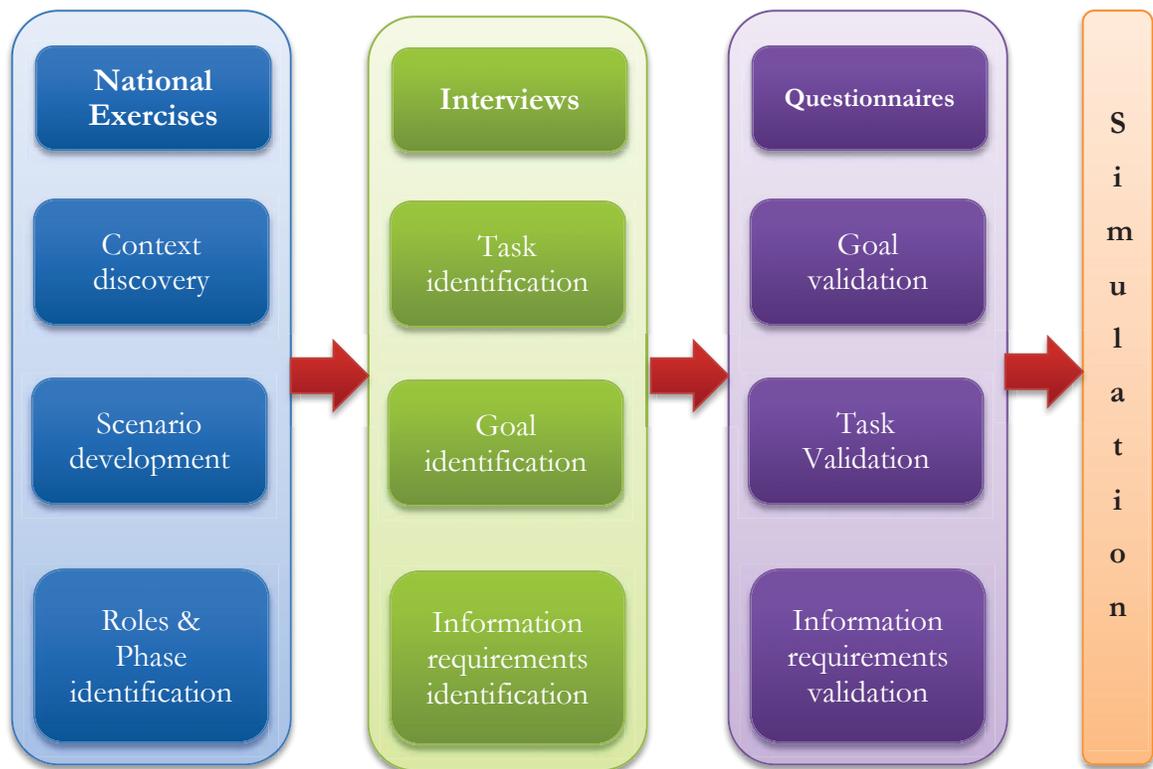
**4.4.1.2 Extended Goal Directed Information Analysis**

For this study, the steps of GDIA, as shown in Figure 4.1 below, are modified to meet the domain requirements while maintaining its validity and objectives intact.



**Figure 4.1 Steps of GDIA (adopted from Prasanna et al., 2009)**

Likewise, GDIA is extended by adding a step called Simulation to validate the gathered requirements in an actual scenario. The adapted steps of extended GDIA (EGDIA) are shown in Figure 4.2 below:



**Figure 4.2 Steps of EGDIA (Javed et al., 2011a)**

The order of these steps is also modified to accommodate the availability of participants (emergency managers). For example, the validation of tasks, goals and their related information requirements was done in questionnaires after the interviews as illustrated in Figure 4.2 above. The tasks, goals, and information requirements gathered during interviews were categorised according to the roles and phases of emergency managers and were used to develop online questionnaires. Emergency managers from all over New Zealand were asked to complete these questionnaires in the context of a tsunami scenario. They were asked to rate each of the information requirements according to the nature and phase of the emergency situation. Out of 17 primary experts from all over New Zealand, 13 participated for each role. Details of these steps are as follows:

### **1. Context discovery**

Preliminary understanding of the emergency context of mass evacuation operations is obtained via the following sources (Hammersley & Atkinson, 1995).

- Face-to-face interviews with relevant emergency managers
- Observations of real time practices in natural emergency exercises; Ruaumoko and Tangaroa

- Formal and informal documentation such as procedure manuals and policy documents produced as part of the emergency response work such as civil defence emergency management (CDEM) plans (MCDEM, 2009), guide to mass evacuation plans (MCDEM, 2008a) etc.

Ethical approval is obtained from the Massey University Ethics Committee regarding the observations and interviews during the national exercises (see appendices A, B, and C). Interview questions are described in Appendix D. This helped in building the basic knowledge required to carry out the rest of the EGDIA steps. Moreover, it also helped in building suitable scenarios from Exercise Ruauumoko for volcanic eruption scenarios and Tangaroa for tsunami scenarios, which are described in the second step of EGDIA.

## 2. Scenario building

ACTA incorporates clearly defined interview probes during its application, the lack of which is a major limitation in GDTA. Among such probes, "Simulation Interviews" are most significant. The Simulation Interview is a type of interview that is specifically based on the presentation of a scenario to the emergency manager. Its aim is to overcome limitations due to the unstructured nature of interviews and to sharpen the focus of participants. Moreover, scenarios are helpful to probe mental models, thinking processes and assumptions of participants by improving their focus and imagination.

**Scenario:** The national exercise Tangaroa is used as a guideline to develop tsunami scenarios by simulating the information feeds. Emergency managers use seismic and related data to register an underwater event (e.g. earthquake or volcanic explosion) that could cause a tsunami. Deep Ocean Assessment and Reporting Tsunami (DART)<sup>16</sup> data is then analysed to confirm whether a tsunami has been generated or not. Once a tsunami has been confirmed, areas of possible devastation are marked and planning for possible evacuation is started. Priority zones or the areas that need special attention, for example schools and hospitals are marked. Similarly, decisions to evacuate, and the time and extent of evacuation, are decided. Planning for the safe evacuation of people, which includes transport, food and shelter, and medical facilities are critical considerations

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<sup>16</sup> <http://nctr.pmel.noaa.gov/Dart/>

since wrong decisions can lead to either unnecessary disruption or increased casualties and economic loss.

### 3. Role and Phase identification

The following main roles/functions are identified in the Group Emergency Operation Centre (GEOC), from interviews, national level exercises and documentation, (MCDEM, 2008a; 2008b, 2009):

- **Planning and Intelligence (P&I):** The P & I function is responsible for forecasting the incident development, anticipating likely needs, and drafting the Incident Action Plan. This role of the GEOC has a strategic scope and provides other team members at the GEOC with situation analysis as the incident develops through various phases of the emergency. This situation analysis is in the form of a report called a situation report (SitRep).
- **Operations:** The Operations function enacts the Incident Action Plan, which makes sure that responders are as focused and aware as possible so they can fulfil the objectives set by the Controller. The Operation is generally responsible for the operational command of resources. This means allocating specific functions to agencies in their areas of expertise, monitoring their performance and providing a communication link between the responders and the other elements of the GEOC, especially Logistics.
- **Logistics:** The Logistics function or Manager ensures the continuity of operations by making sure that there are sufficient resources (e.g. personnel, vehicles, machinery, buildings, food supplies, medical supplies, tents etc.) on site and within GEOCs.
- **Welfare:** The Welfare function is responsible for the wellbeing of affected people during or after the emergency situation, especially in the case of evacuees. The Welfare personnel set up temporary welfare camps and provide accommodation, food and basic medical facilities until required.
- **Controller:** The Controller is responsible for the overall incident progression and has overall accountability for the incident. The Controller's responsibilities include:
  - Safety of staff and public
  - Overall operation of GEOC

- Approval of Situation Reports issued by the GEOC
- Incident stability, i.e. the strategy that will be most effective at resolving the incident with economical use of resources. This strategy is issued through the use of the Incident Action Plans (IAPs)
- Property conservation, which relates to the overall damage limitation

An emergency situation involving mass evacuation is divided according to the following phases so that information requirements can also be contextualized according to them and right information can be provided at the right time.

- **Pre-Tsunami Confirmation Phase:** An earthquake has been confirmed but it is not confirmed whether a tsunami is generated at the source or not.
- **Tsunami Confirmed Pre-Decision Phase:** A tsunami has been confirmed but a decision has not been. Threat level is being confirmed.
- **Evacuation Decision Phase:** A tsunami has been confirmed and an evacuation decision is being made about time and areas of evacuation.
- **Evacuation Phase:** The evacuation decision has been made and people are being evacuated
- **Post-evacuation Phase:** Evacuation has been completed and people are in welfare centres.
- **Return Phase:** People are returning to their homes.

#### 4. Tasks elicitation validation

Each step in the development of a scenario involves the identification of tasks performed by each role. Each selected emergency manager is asked to:

- Describe the possible activities they carry out under the described scenario
- Identify possible task groupings and sub-tasks
- Equal opportunity is given to both experienced and novice emergency managers to avoid any bias and to capture complete and accurate requirements.

Identified tasks for each role are presented in Appendix E. After collecting the task lists from various emergency managers, the data is analysed to develop the task structure. The intention of this analysis is to identify tasks so they can be used together with the

scenarios during the next step of the research to determine the cognitive demands of individual emergency managers.

Moreover, tasks identified from one emergency manager are compared with the tasks from the other one in the same role to find the common ones. In addition, a task missed by one participant was confirmed for validity by reminding him/her about it. Further, his/her discussion about the task is considered to understand the value and importance of the task. Two main tasks identified for the Planning and Intelligence function are:

- Developing situation report (SitRep)
- Developing Incident Action Plan (IAP)

These two tasks are carried forward as an example to identify the information requirements.

#### **5. Goal elicitation and validation:**

Semi structured interviews were conducted with the emergency managers to identify the goals and sub-goals that were expected from the situations under investigation. Initially, ten emergency managers were interviewed during exercise Tangaroa on two shifts. Each manager was an active member of a GEOC and was an expert in one of the five main functions, i.e. Controller, Planning and intelligence, Operations, Welfare, Logistics.

In this exercise, tasks identified in the previous section are used as probes to unveil the cognitive demands or goals, i.e. why each task was selected. Specific task probes and scenarios are expected to control and guide the interviewing process. The goal hierarchy forms the basis for deriving information requirements. Thus, it is very important to make sure that the developed goal hierarchy is meaningful and accurate. At this level of the process, it was very useful to check the validity of the derived goal structures. A larger group of emergency managers (18 members), which included emergency managers from various EOCs in the area and managers previously interviewed, validated the goals identified two days after exercise Tangaroa on exercise debriefing day. The elicited goals from each member were cross checked with others for validation. The following steps illustrate this validation process:

- The developed goal structure is distributed among the interviewed emergency managers

- Discussions with the previously interviewed emergency managers to revisit the developed goal and sub-goal structures so that doubtful elements can be removed
- To represent generic goals of the domain being investigated; the results are validated by discussions with different emergency managers who represent other Emergency Operation Centres (EOCs) of the same region.
- Modifications of the goals and sub-goal structures based on the comments and suggestions

To represent generic goals of the domain being investigated; the results are validated by discussions with different emergency managers who represent other Emergency Operation Centres (EOCs) of the same region. Main goals associated with the tasks mentioned above are:

- Provide an up to date analysis of the prevailing situation to decision makers
- Provide a plan to carry out safe evacuation of the area under risk

## **6. Information elicitation and validation**

The information required to make decisions and carry out the tasks is obtained from the identified goals and sub-goals. To ensure that the obtained goals, decisions, tasks and their information requirements are complete and accurate, validation with a larger group of emergency managers representing other similar organisations in and outside the region is done. The validation process is expected to improve the generalisation of the findings. In this manner, the findings of the study will become a closer representation of the requirements of a much wider domain, such as a country, rather than one that is limited to a single district or region. Later, the feedback obtained is integrated with the feedback of emergency managers representing outside regions. Such integrated feedback could then be used to make the necessary corrections to the identified information requirements. In addition, possible sources of information and the next destination of analysed information is also queried and validated to enable the modelling of information flows between different roles. The step wise sequence is illustrated in Figure 4.2 above.

## 7. Validation in simulation

The requirements analysis allowed us to develop a prototype called Situation Aware Vigilant Emergency Reasoner (SAVER). The style in which information is provided to the emergency managers greatly influences their ability to make a good decision in reasonable time. Information requirements acquired in previous steps provide information to emergency managers via SAVER in a simulated scenario. This step was supposed to find any missing requirements or to identify problems with the existing information requirements. Participants were asked to perform tasks like preparing a situation report. Information needed for the task was provided via SAVER. Later, participants were asked whether they needed more information than was presented to see if any information was missing. Moreover, participants were asked if there was anything wrong with the content or format of information presented. The next section details the final validated information requirements for various roles of users over the different phases of a mass evacuation operation.

### *4.4.1.3 Information requirements*

To validate goals, tasks and information requirements, questionnaires were circulated to the GEOCs all over New Zealand to get feedback from the wider community. In all the following tables, the first column shows the phases of emergency, the second column shows the information requirements of each role during the respective emergency phase, and the third column, “%R”, shows the percentage of participants out of the total participants who mentioned the identified information requirement as relevant. Though there is no method available to find an accurate amount of information requirements needed to achieve desired levels of SA, a certain number of information requirements can be validated as “appropriate to achieve the goals” by multiple domain experts. Moreover, initially the information requirements, which are declared as related by 75% or more, are included in the final requirements and the ones which are mentioned as irrelevant by more than 25% are discussed with the participants to know the reasons. In addition, after mutual understanding with the domain experts (emergency managers), the criteria for rejecting an information requirement by declaring it irrelevant is fixed at 75%, however, none of the information requirements was mentioned as irrelevant by 75% or more participants, therefore none was rejected. The three main objectives of this validation via the questionnaires are:

1. To discover any problems with the roles, goals, tasks, and their corresponding information requirements
2. To add (if any) role, task, goal, or information requirements that are missed out
3. To determine what the wider community of emergency managers all around New Zealand think about the roles, tasks, goals and information requirements relevant to the phases of emergencies and the roles of emergency managers

See Table 4.1 for information requirements of the planning and intelligence (P&I) role.

**Table 4.1 Planning and Intelligence (P&I) function information requirements.**

Emergency phase	Information requirements (Planning & Intelligence)	% R
Pre-Tsunami Confirmation phase	Detail on the magnitude, location, time of earthquake (tsunami source)	100
	The analysis of earthquake/tsunami information is required	100
	Deep-Ocean Assessment and Reporting Tsunami (DART) Data from National Oceanic and Atmospheric Administration (NOAA).	100
Tsunami confirmed-Pre Decision phase	Information required for activating the GEOC	100
	The contact details of staff are required	100
	Direction, speed and height of waves from various DART sensors in the ocean along with the surrounding geographical data are required	92
	Information will be needed as to whether there is a way to stop the water reaching populated areas, e.g. using sandbags etc.	92
	<b>To develop a situation report, P&amp;I requires information on:</b>	
	US Geological Survey report on earthquake and its analysis	100
	DART data	100
	NCMC advice or warnings about the current status	100
	Situation reports from the LEOCs	100

	Miscellaneous information, e.g. maps of areas at risk, declaration of national warnings, media releases	100
Evacuation decision phase	<b>To develop an Incident Action Plan (IAP), P&amp;I requires:</b>	
	Area to be evacuated	100
	Population of the area	100
	Number of facilities in the area which require special attention e.g. schools and hospitals etc.	100
	Number of self-evacuees till now	100
	People who will need assistance	100
	Nearest safe zones to evacuate	100
Evacuation phase	The current figure of total evacuees	92
	The safety of the evacuation routes	100
	The current status of DART data	50
Post evacuation phase	The water levels in the affected area	92
	Future risk of rise in water levels	100
	Welfare conditions of evacuee camps	92
	Which other locations need attention	83
Return Phase	The condition of evacuee accommodation	69
	Number of self-returning evacuees	61
	Evacuees needing help for return	100
	The resource requirements of evacuees for return	100

Table 4.1 summarizes the responses about the validation of information requirements for the Planning and Intelligence (P&I) role. Obviously, P&I being central to information gathering, processing, planning and dissemination has the highest number of information requirements. All information requirements of the “Pre-Tsunami

confirmation phase” are relevant, as a tsunami is only generated if the magnitude of earthquake is high enough and the earthquake is in water or very close to coastal areas. During the second phase “Tsunami confirmed pre-decision phase”, seven out of nine information requirements are identified as relevant by 100% of participants as information such as direction, speed and height of incoming waves help to identify areas at risk and the likely arrival time of waves, essential to decide the time of evacuation. With three exceptions, all the information requirements gathered for all remaining phases are marked as relevant. “Updated DART data” for “Evacuation phase” is mentioned as not relevant, which is very interesting, as participants perceive that once the evacuation areas are defined and evacuation is under way this information is no longer necessary. This is not the case as if the waves change their course, speed or height; the evacuation plan may need updating or changing too. This was confirmed later by discussions with some of the participants who mentioned it as irrelevant. Similarly, 31% of participants recommend “The condition of evacuee accommodation” as irrelevant to “Return phase”, whereas it is important information to decide whether evacuees should return or not. Finally, 39% mentioned that “Number of returning evacuees” as not relevant information; this is mainly because no support is being provided to self-returning evacuees so keeping track of them is irrelevant.

Table 4.2 illustrates the detailed information needs of the Operations function according to different phases of a mass evacuation operation.

**Table 4.2 Operations function information requirements**

<b>Emergency phase</b>	<b>Information requirements (Operations)</b>	<b>% R</b>
Tsunami confirmed Pre Decision phase	Information on current situation	100
	Update from other organizations or NCMC to keep GEOC updated	100
	Information on assigned tasks by the Controller	92
Evacuation decision phase	Information on the lead organization, usually police, to lead the evacuation	92
	Information on how to contact organizations like police and fire service	92

	Information on who are contact persons in various organizations	100
	What is the response by external organizations	69
Evacuation phase	Require situation reports and Incident Action plans to see whether everything is going according to the plan	85
	Result of previous actions/decisions	92
	The co-ordination between NCMC, GEOC, LEOC and within GEOC	100
	Information on responses by external organizations to monitor their progress	100
	Incident action plan is required to identify the required resources	92
Post evacuation phase	Progress of welfare services in evacuee camps	69
	Updated water levels to update plans	61
	Which other locations will need attention to update plans	92
	The resource usage in comparison to plan	92
Return Phase	The updates from organizations providing welfare	100
	Number of evacuees needing help for return	77
	Resource requirements of evacuees to return	92

All the information requirements gathered for the “Tsunami confirmed pre-decision phase” and “Evacuation decision phase” are marked relevant. However, 69% of the participants think that the requirement “what is the response by external organizations” is relevant. Moreover, the remaining 39% of participants think it is more relevant to “Evacuation phase” when some response from other organizations is expected. “Progress of welfare services in evacuee camps”, is declared relevant information to the “Post Evacuation phase” by 69% of the participants who suggested that it is more relevant for the role of Welfare function instead of Operations, whereas, after discussion with respondents it is affirmed as relevant since the Operations function also has to monitor the processes of other roles. Information requirements for all the other

phases are declared as relevant except “Updated water levels”, which is redundant information during the “Post evacuation phase”, since evacuation is already completed, however, this information is more relevant to the “Return phase”.

Table 4.3 shows the detailed information needs of the Logistics function during a mass evacuation operation.

**Table 4.3 Logistics function information requirements**

<b>Emergency phase</b>	<b>Information requirement (Logistics)</b>	<b>% R</b>
Tsunami confirmed Pre Decision phase	Information on to how to contact staff of GEOC	100
	Information on what resources are likely to be required in future	92
	Information on the process of acquiring the required resources	100
	Information on time required to arrange the required resources	100
Evacuation decision phase	Information on which resource is required in what quantity	92
	Information on available resources	100
	Information on the current location of resources	92
	Information on how to contact person or organization	100
	Information on what resources are in use and where	100
	Information on which resource requests are pending	100
Evacuation phase	Information on where resources are currently being used	100
	Information on resources being released to be used elsewhere	100
	Information on staff availability for planning	92
	Information on progress of evacuation so that more resources can be deployed if needed	92
Post evacuation phase	Information on location of resources after release	92
	Information on resources deployed in the welfare camps	77
	Information on resource usage to plan future needs	92

	Information on resources used during evacuation	100
Return Phase	Information on resources required for return of evacuees	92
	Information on resources beings used for return	85
	Information on resources returned to respective organizations	100

The logistics function is not fully active during the “Pre tsunami confirmation phase” as nothing is confirmed yet, therefore no information requirements are identified for this phase, although information requirements gathered for the other phases are relevant. This shows that the requirements gathered for the logistics function were quite comprehensive and appropriate.

Table 4.4 explains the detailed information needs of the welfare function during various phases of a mass evacuation operation.

**Table 4.4 Welfare function information requirements**

<b>Emergency phase</b>	<b>Information requirement (Welfare)</b>	<b>% R</b>
Evacuation decision phase	Information on area to be evacuated	100
	Information on number of people to be evacuated	100
	Information on type of people (old, young, children)	100
	Information on how long the resources are needed in the welfare camps	100
	Information on process of resource gathering for the welfare camps	92
	Contact information of people and organizations for resources	100
	Information on who needs assistance and of what type	92
Evacuation phase	Information on number of evacuees arriving at welfare camps	100

Post evacuation phase	Information on resources being used in welfare camps	85
	Information on people in the welfare camps	77
	Information on future resource needs of welfare camps	100
Return Phase	Information on people leaving the welfare camps	93
	Information on resources used in welfare camps	85

The welfare function is active only when a tsunami generation is confirmed and a decision for evacuation is being made at the third phase of an emergency according to our classification. Therefore, there are no information requirements identified for the first two phases. All the information requirements gathered for the remaining phases are marked as relevant.

Table 4.5 illustrates the detailed information requirements of the Controller during a mass evacuation.

**Table 4.5 Controller function information requirements**

<b>Emergency phase</b>	<b>Information requirement (Controller)</b>	<b>% R</b>
Pre-Tsunami Confirmation phase	Information on the current situation from NCMC and other organizations e.g. magnitude of earthquake, location, and depth of source.	100
	Overall situation picture by information from NCMC	92
	Current response from other sectors and groups	77
Tsunami confirmed Pre Decision phase	Situation reports for approval and decision making	85
	Incident Action Plans for approval	92
Evacuation decision phase	Updated situation reports for approval and decision making	85
	Updated Incident Action Plans for approval	85
Evacuation phase	Information on safety of response teams and evacuees	100
	Status of evacuated area and number of evacuees	92

Post evacuation phase	Evacuee status in welfare centre	85
	Resource status in welfare centres	77
Return Phase	Current situation for homes and other facilities to decide the return of evacuees	77
	Prediction about future situation to decide the return of evacuees	92

As the Controller has to approve most of the actions and decisions most of the overall information goes to him/her. Except for three information requirements, all the information requirements are marked as relevant by 85% or more of the participants. Only 23% of participants think that “response from other sectors and groups” is not relevant since the tsunami has been confirmed. Similarly, “resource status in welfare camps” is not relevant to the Controller as Welfare function maintain these resources though the Controller can approve the request if more are required.

In survey responses, it is suggested that the “tsunami confirmed pre-decision phase” does not add much to the representation of the emergency situation so it should be merged with the “tsunami confirmed evacuation phase” as once the tsunami is confirmed, information is gathered and processed to develop an evacuation plan that includes the evacuation decision.

#### 4.4.2 The SAVER system

A prototype system dubbed *Situation Aware Vigilant Emergency Reasoner* (SAVER) is designed based on the SA requirements of the emergency managers during a mass evacuation operation. Moreover, ontology based SA is employed to meet the dynamic requirements of emergency situations.

##### 4.4.2.1 Ontology-based Situation Awareness

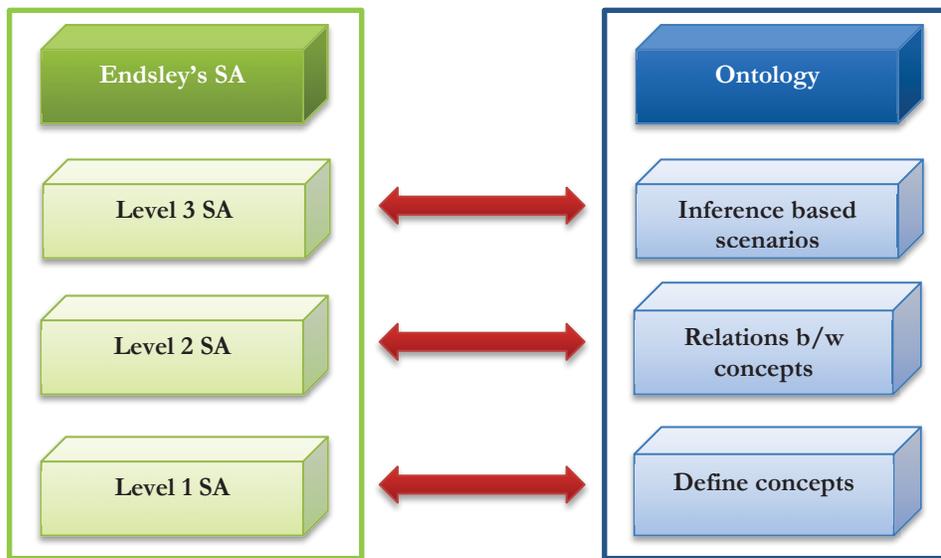
Ontology is defined (Gruber, 1993) as:

*“A formal, explicit specification of a shared conceptualisation”*

Hence, ontology provides a shared vocabulary, which can be used to model a domain, i.e. the type of objects and/or concepts that exist in a particular domain of interest, and their properties and relationships with one other. As discussed in Chapter 2, Matheus et

al., (2003; 2005) have proposed ontology based SA systems. They also provided higher level ontologies to capture generic situation descriptions that can be contextualized to derive more domain specific ontologies. At the same time, ontology can be used to model an evolving situation by combining it with a reasoner that can check the validity of the modelled domain and draw inferences by applying rules and axioms for constraints, restrictions and functional dependencies (Smirnov et al., 2010).

Figure 4.3 below shows the connection between the ontology elements and Endsley's levels of situation awareness. This research extends these concepts to the use of ontology and inference to make projections at Endsley's third level of SA (see green boxes in Figure 4.3). At the same time, it will help to integrate information from diverse sources (Smirnov et al., 2003).

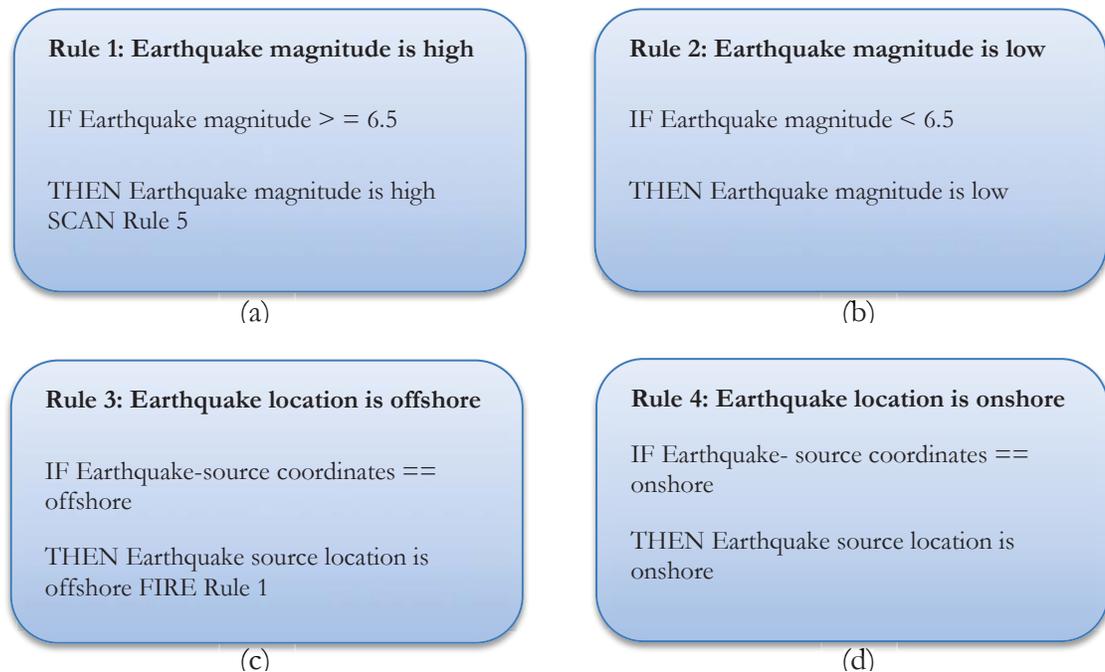


**Figure 4.3 Ontology based situation awareness (Javed & Norris, 2011)**

Data received from various sources is provided to the ontology that compares it with the domain knowledge, infers what is relevant to the prevailing situation, and displays the relevant data to present Level 1 SA. Moreover, ontology relates this data with the domain knowledge part of the ontology and generates the possible explanation of the situation that is Level 1 SA. In addition to this, the reasoner infers the possible future states of data captured by using forward chaining inference (Blachowicz, 2009; Laudan, 1981) on the domain knowledge and rules to generate Level 3 SA. In a forward chaining rule based inference system, knowledge is organised in the form of IF-Condition, THEN-actions. In this way, rules used by human experts can be represented in an expert system. When a condition is satisfied an expert makes a decision, similarly when

all the conditions in the IF portion of a rule are satisfied, an expert system performs the actions in the THEN portion of that rule. Firing of a rule adds more information from the action part and invokes other rules. Hence, all of this chain reaction can start from very little initial information as an input. Moreover, this process will keep generating more and more information by firing various rules until the desired criteria are reached. The inference process goes on until either a goal is reached or no more rules can be fired due to the limited initial information or knowledge base or both.

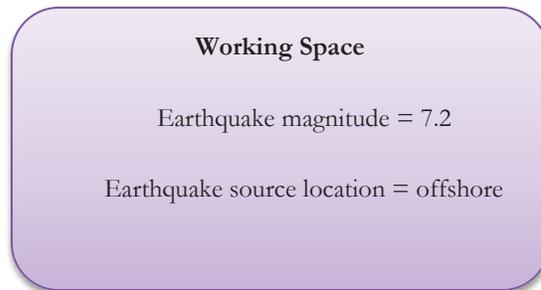
For example, consider a very simple scenario of tsunami risk after an earthquake. Sensors provide information on earthquake magnitude, source location, and depth. Moreover, DART sensors in the ocean provide wave information. The forward chain-based inference system scans the rules sequentially and fires the first rules whose conditions match the contents of the working memory. Therefore, to detect whether a certain earthquake can generate a tsunami or not, the following general rules (see Figure 4.4 below) and initial information are required:



**Figure 4.4 Example rules for detecting tsunami generation from earthquake information**

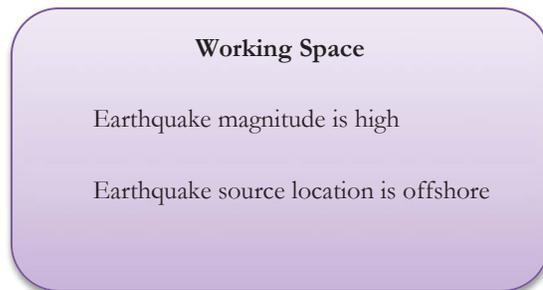
Therefore, the first step in the operation of this system involves the acquisition of sensor readings about earthquake magnitude and earthquake source location. Once

these values are available, the initial state of the working space will be as given in Figure 4.5.



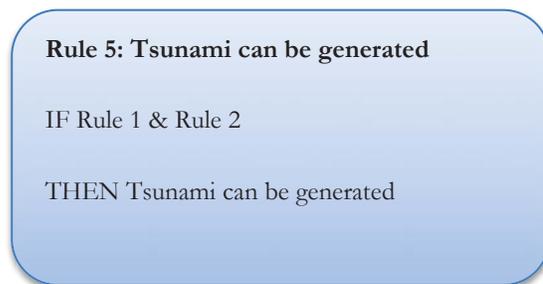
**Figure 4.5 Initial state of working space**

Now, the system will check the sensor readings and convert them to information using the rules 1, 2, 3 and 4. The following information (Figure 4.6) will be added to the working space.



**Figure 4.6 State of working space after rules scanning**

Moreover, Rule 5 given below in Figure 4.7 is fired when both Rule 1 and Rule 2 are fired and generates the information: “Tsunami can be generated”



**Figure 4.7 Rule for tsunami generation**

Once it is clear that a tsunami is generated, another set of rules is fired based on wave parameter data from DART sensors. This data is then used to calculate the arrival time and probable impact of the tsunami on at risk coastal areas. Since ontology is modelled

using a formal language it is in machine-readable form and available for automatic processing by a computer based agent or program. The situation information modelled in ontology is available and it can be shared automatically with other systems. In addition to this, ontology provides the higher level of completeness in the description of procedures, required by successful automation (Viinikkala, 2004).

#### ***4.4.2.2 Other advantages of ontology in SAVER***

There are also many other advantages of using ontology in working and the operation of SAVER considering the dynamic requirements of emergency situations. For example:

1. It can solve problems of heterogeneous data input since data sources are created and maintained for personal and specific needs, using ontology they can be re-used in other tasks for other purposes by semantic integration.
2. In large scale disasters, many organisations work together, communication and co-ordination between them is vital for the overall combined operations. However, different terms have different meanings in various fields, departments and organisations. Therefore, it is difficult to provide all meanings in a single system. Ontology can solve this problem by semantically integrating different meanings to offer a definition that is acceptable to all. If SAVER becomes successful for a small group of people, by using ontology, it would be easy to extend it for multiple organisations interacting in emergency management.
3. The explicit specification of domain concepts in ontology defines the meanings of the concepts and the constraints of their usage (Studer et al., 1998; Uschold & Gruninger 1996). Ontology is formally represented using a well defined language so that it is machine readable (Uschold & Gruninger 1996). To address the problem of semantic interoperability and to allow machine automation of data integration, it is desirable that the semantics of the data are defined explicitly and represented in a machine processable way. Explicit and formal ontologies can help SAVER define the semantics of the data, make them sharable by different users and allow machine processing. Hence human intervention is minimised and errors are reduced by decreasing their workload.
4. Standard top level ontologies for situation modelling are available that can be used to develop domain specific systems. The number of these ontologies is continuously increasing.

5. Using the Web Ontology Language (OWL) to model an ontology based situation allows an easier and more meaningful exchange of information rather than Extensible Mark-up Language (XML<sup>17</sup>) alone. OWL can also be used to exchange information with some other standards, e.g. Emergency Data Exchange Language - Common Alert Protocol (EDXL-CAP). EDXL-CAP is a format for exchanging all-hazard emergency alerts and public warnings over all kinds of networks. CAP<sup>18</sup> allows a consistent warning message to be disseminated simultaneously over many different warning systems thereby increasing warning effectiveness while simplifying the warning task.
6. Ontology based systems can integrate information from diverse sources, e.g. ontology based schemas will not only use the table names specified in the query, but also the tables which are semantically the same but have different names. This is because OWL-aware tools can determine if two classes or individuals are the same or different (Tran et al., 2007).
7. In ontology based systems, tables, in the form of classes, and relations in the form of properties, can be added or modified at run time if required making them very flexible to model evolving and dynamic situations.
8. As more and more web applications are moving towards web 2.0, ontology based systems will be able to search the web effectively and efficiently for information needed to respond to emergency situations.
9. With dynamic binding in ontology, a class or a sub-class can exhibit a specific behaviour of itself, parent class, any particular parent class, or of any other class depending on the type specified in a methods call at run time. In contrast, in an ordinary object model concepts can only inherit the properties of parent concepts.
10. Ontologies with limited scope can scale well in real world applications with less development effort since agents can populate them automatically (Shadbolt et al., 2006).
11. Ontology can be used to make a standard for information exchange that is expressive, meaningful and flexible. As standards also bring inter-operability, such a system can easily help in providing semantic exchange of information.

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<sup>17</sup> <http://www.w3.org/XML/>

<sup>18</sup> <http://docs.oasis-open.org/emergency/cap/v1.2/CAP-v1.2.html>

Though all of the above mentioned advantages are not implemented and tested in this project, these can be very useful in addressing many issues related to the dynamic requirements of emergency situations and can easily be added if the whole architecture of the system is based on ontologies.

#### ***4.4.2.3 System architecture for SAVER***

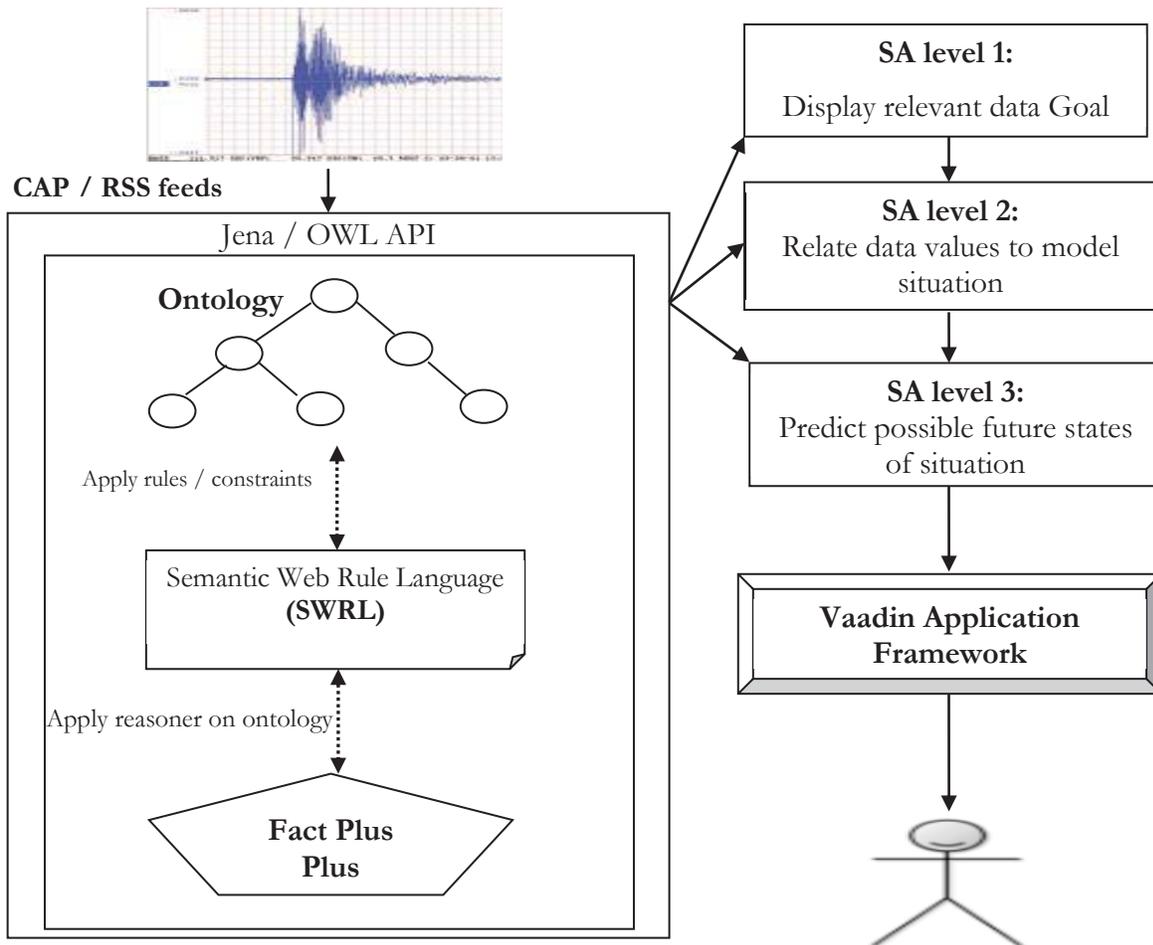
The main objective of the system design in this research is to receive information from various sources in real time and integrate it in a meaningful way. Other objectives include representation of information according to the requirements of three levels of situation awareness. Therefore, the system architecture is designed to receive information from various web sources like Common Alert Protocol (CAP) or Really Simple Syndication (RSS<sup>19</sup>). CAP is an XML-based data format for exchanging public warnings and emergencies between different alerting technologies and RSS feeds are used to publish frequently updated forums like news headlines, blog entries etc.

SAVER can comprehend the meaning of the information according to the domain knowledge of the emergency situation. SAVER can not only model the current situation based on the incoming information and information requirements, it can also provide future states of a situation using ontology inference based on rules (as explained in the previous section) and constraints defined on relationships (properties) of domain concepts (classes). Domain knowledge is represented by using the OWL as explained in Chapter 3.

The system architecture of SAVER is shown in Figure 4.8 below:

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<sup>19</sup> <http://www.w3schools.com/rss/>



**Figure 4.8 SAVER system architecture for Situation assessment**

Once an earthquake occurs, its detail is posted via CAP/RSS sources<sup>20</sup>. This data is acquired by the SAVER and placed in a working space (computer memory) where all the processing is done. The data is then added to the ontology as a value property of a concept and lines similar to the following Figure 4.9 are inserted into the ontology file.

```

<owl2xml:DataPropertyAssertion>
  <owl2xml:DataProperty owl2xml:URI="&SAVERExample3;hasEQMagnitudeValue"/>
  <owl2xml:Individual owl2xml:URI="&SAVERExample3;magnitude1"/>
  <owl2xml:Constant owl2xml:datatypeURI="&xsd,float">8.1</owl2xml:Constant>
</owl2xml:DataPropertyAssertion>

```

**Figure 4.9 OWL snippet showing data value assertion for earthquake magnitude**

<sup>20</sup> [http://www.incident.com/cookbook/index.php/Public\\_CAP\\_Feeds](http://www.incident.com/cookbook/index.php/Public_CAP_Feeds)

This example states that an earthquake of magnitude 8.1 has occurred. Similarly, other details e.g. source location, depths etc., are also added. Now, a reasoner (FACT++) checks the changes in ontology for integrity and compares newly added values with the SWRL rules and OWL axioms. The rule for an earthquake incident to be classified as a high intensity earthquake is shown in Figure 4.10 below.

```
<owl2xml:EquivalentClasses >
  <owl2xml:Class owl2xml:URI="&SAVERExample3;HighIntensity"/>
  <owl2xml:DataSomeValuesFrom>
    <owl2xml:DataProperty owl2xml:URI="&SAVERExample3;hasEQMagnitudeValue"/>
    <owl2xml:DatatypeRestriction>
      <owl2xml:Datatype owl2xml:URI="&xsd;float"/>
      <owl2xml:DatatypeFacetRestriction owl2xml:facet="&xsd;minInclusive">
        <owl2xml:Constant owl2xml:datatypeURI="&xsd;double">6.5</owl2xml:Constant>
      </owl2xml:DatatypeFacetRestriction>
    </owl2xml:DatatypeRestriction>
  </owl2xml:DataSomeValuesFrom>
</owl2xml:EquivalentClasses >
```

**Figure 4.10 OWL snippet showing rule for high intensity earthquake**

The above snippet of OWL is just a description of how an equivalent OWL class is defined using rules and criteria. Therefore, whenever an earthquake of magnitude more than 6.5 occurs it will be classified as a high intensity earthquake. As various rules fire, information is added to the working space and other rules are also activated, if required. When the information added to the working space meets the SA requirements of a user, in the user ontology, information is presented to the user via a web interface.

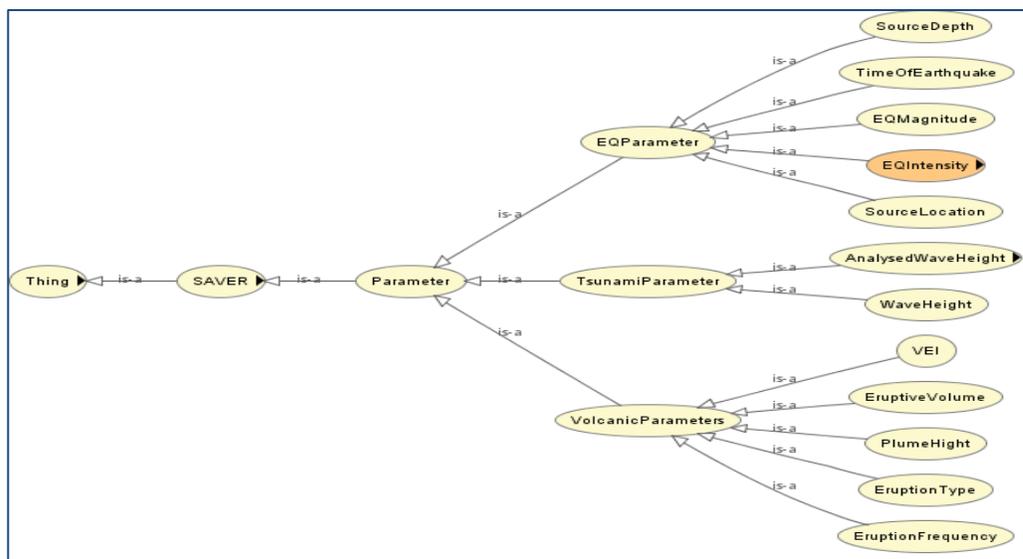
#### ***4.4.2.4 Ontologies developed for SAVER***

The use of ontologies is central to the design of SAVER as described in previous sections. The architecture uses ontologies expressed in OWL for situation modelling, domain modelling, situation inference and reasoning, supporting automatic information fusions. Please see section 4.4.2.2 “Other advantages of ontology in SAVER” for details of ontology applications in SAVER. Four types of ontologies are used in SAVER:

1. Domain Ontology
2. Application Ontology

3. User Ontology
4. Information requirements Ontology

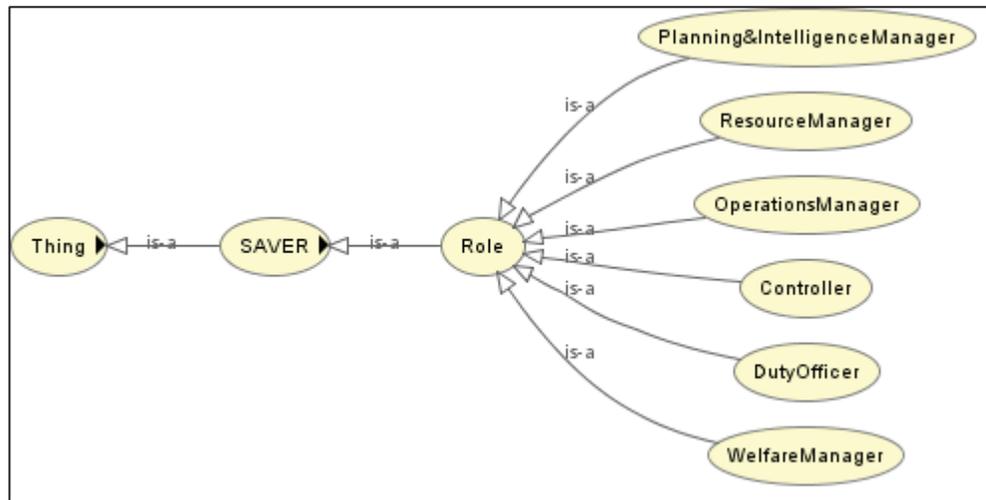
The reason for keeping the domain knowledge separate from the application knowledge and user knowledge is their potential re-usability in other contexts, as we will see in upcoming chapters. All ontologies are consolidated under a main SAVER ontology. Domain ontology uses the concepts from the field of disaster management specifically from the domain of tsunami risk. Therefore, it contains the parameters of tsunami scenario domain and relationships between the domain concepts. See Figure 4.11 for graphical representation for part of a domain ontology.



**Figure 4.11** Fragment of ontology showing earthquake & tsunami parameters

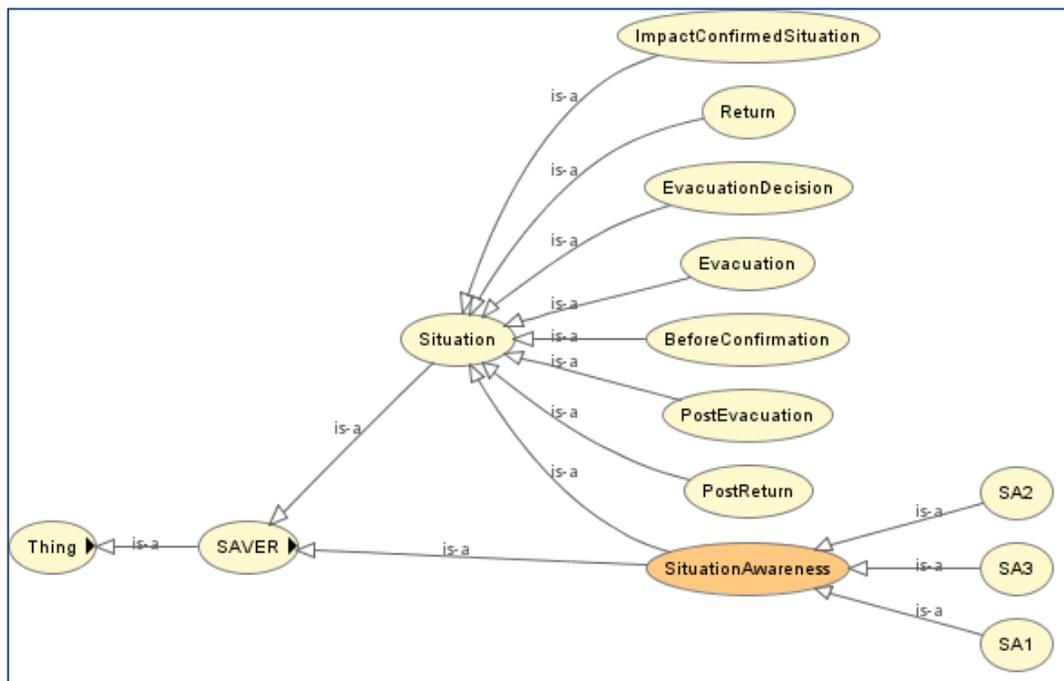
Concepts like *EQParameter*, *SourceDepth*, *TimeOfEarthquake*, *EQMagnitude*, *SourceLocation*, *TsunamiParameters*, and *AnalysedWaveHeight* are from the domain ontology. An **Is-a** relationship is a way of identifying concept hierarchy. For example, *EQMagnitude* **is-a** kind of concept *EQParameter*. Figure 4.12 below shows various concepts of the User ontology. It describes various kinds of roles that users can have, e.g. *Planning&IntelligenceManager*, *ResourceManager*, *OperationsManagers*, *Controller*, *WelfareManager*, etc. all of which are represented as concepts. This ontology has details of the various responsibilities, roles. Moreover, information requirements gathered in the previous section are present in information requirements ontology. SAVER uses these details by

performing inferences on them to find the related information requirements for a specific role in a specific situation.



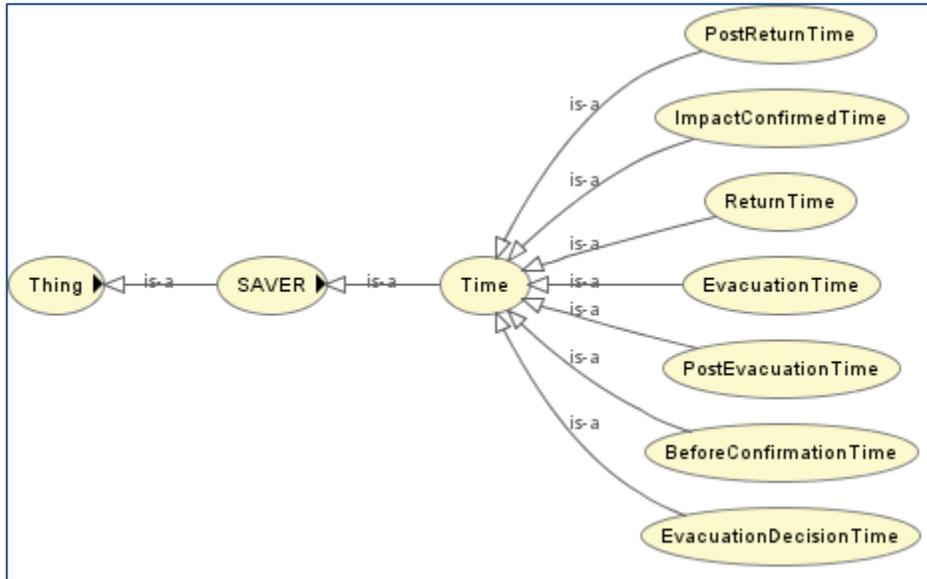
**Figure 4.12** Fragment of ontology showing various roles

Similarly, Figure 4.13 below expresses some of the concepts of the Application ontology. Application ontology uses the SAWA situation ontology (Matheus et al. 2003) on the top. The concept *Situation* can have different possible subtypes i.e. *Situation BeforeConfirmation*, *EvacuationDecision*, *Evacuation*, *PostEvacuation*, *Return*, *PostReturn*. Moreover, *SA1*, *SA2* and *SA3* represent three levels of situation awareness.



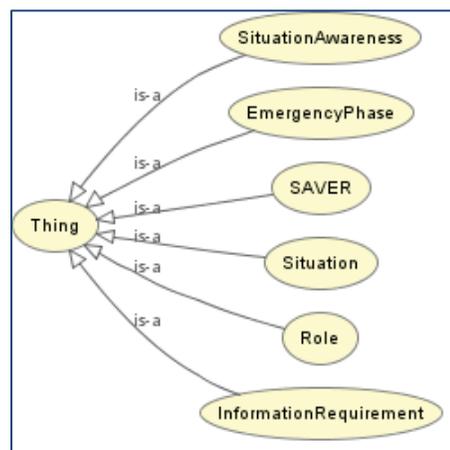
**Figure 4.13** Fragment of ontology showing situation awareness representation

Figure 4.14 below demonstrates the concept of time with its sub-classes in Domain ontology. The time class can have a different type of sub-classes i.e. *BeforeConfirmationTime*, *EvacuationDecisionTime*, *EvacuationTime*, *PostEvacuationTime*, *ReturnTime* etc. These different types of Time class are used to describe different phases of an emergency situation during a tsunami risk.



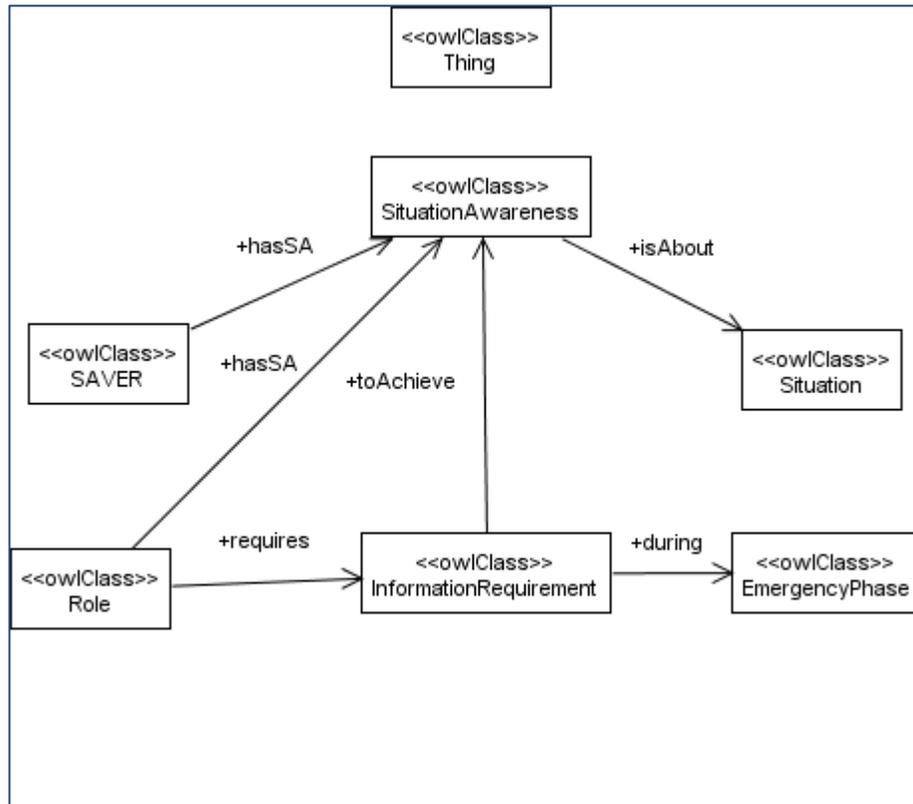
**Figure 4.14** Fragment of ontology showing different phases of tsunami

Situation ontology combines all the ontologies, i.e. Domain ontology, Application ontology, User ontology and their extensions, which are described in upcoming chapters. Figure 4.15 gives an abstract view of these consolidated concepts in SAVER ontology.



**Figure 4.15** Situation ontology showing different concepts on abstract level

Apart from hierarchical relationships like **is-a**, these ontologies are also extended by relationships shown by **+objectPropertyName** between the concepts such as **requires** and **hasSA**. For example, the part of the ontology in Figure 4.16 shows that *Role* **hasSA** *SituationAwareness* and *Role* **requires** *InformationRequirements*. Since concepts *SAVER* and *Role* have the same object property **hasSA**, they will be classified as the same concept by the reasoner, unless they are described as disjoint concepts.



**Figure 4.16 Object properties showing relationships between various concepts**

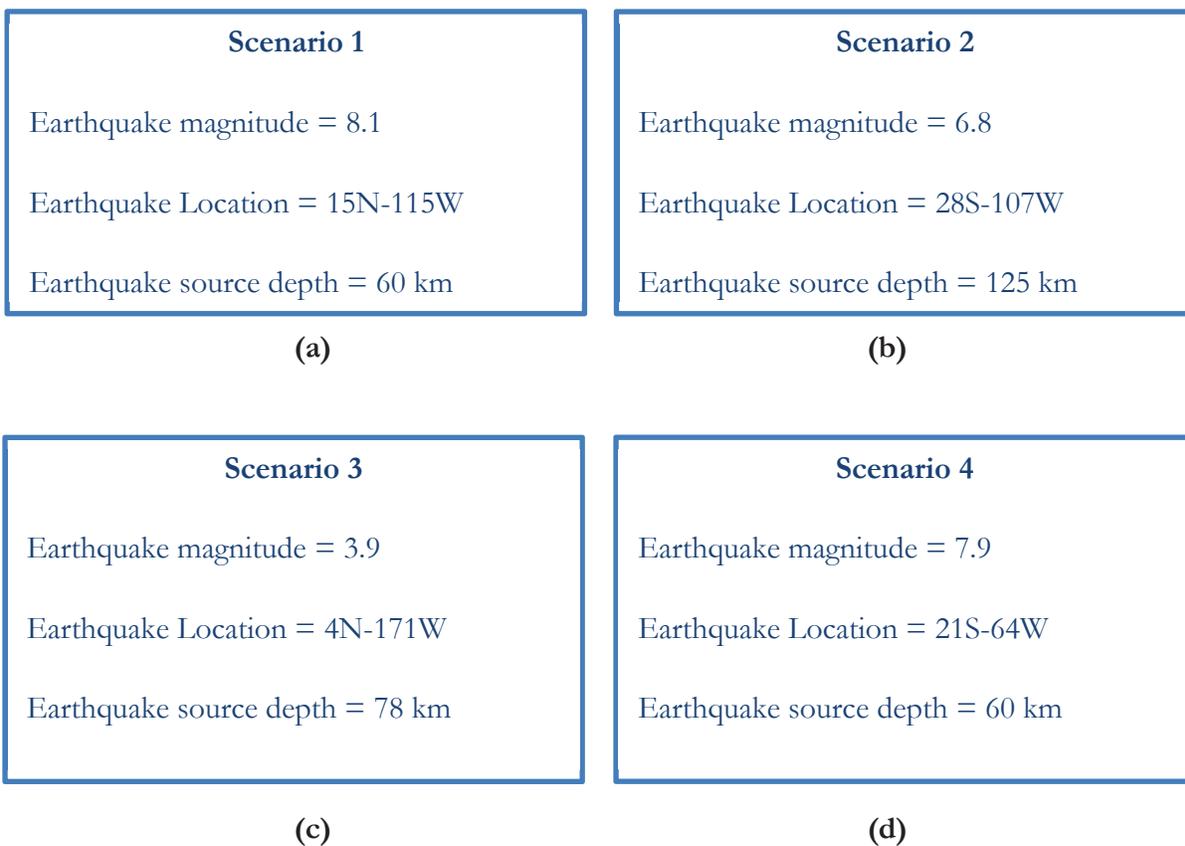
Similarly, ontologies also have some more complex relations that depend on various conditions, e.g. *Earthquake* **canCause** *Tsunami* depending on some conditions i.e. earthquake magnitude should be high enough and its source should be offshore or close to the shore. These relations are also described in the form of rules and axioms as described in the previous section. The complete graphical representations of the asserted and inferred SAVER ontologies are available in Appendix F.

## 4.5 Evaluation

SAVER is evaluated for inference capabilities using test case scenarios. The tests check whether inference and suggestions based on ontology based situation modelling and rules are correct and useful.

### 4.5.1 Scenarios for evaluation

Four different scenarios of earthquakes, different locations, different magnitudes and sources located at different depths are used. The reason for using different combinations is to see how successful ontology based modelling is in a variety of situations and how ontology based inference will transform incoming information into meaningful and useful information. The different scenarios are as shown in Figure 4.17 below:



**Figure 4.17 Four different scenarios used in simulations**

Each of these scenarios is divided into three stages according to the first three phases of the emergency situation. In stage 1, earthquake attributes such as magnitude, source location etc., are processed; in stage 2, wave information from the sensor closest to the

source location is processed. In the last stage, wave information from all the available active sensors is processed to see the direction of wave propagation and amplitude to predict the areas under tsunami threat and level of threat.

#### 4.5.2 Simulated output from SAVER

The data about time of each earthquake and the consequent emergency phases are omitted from the tables for clarity. DART data from the sensors is also omitted here but details are provided in Appendix G. For all scenarios, SAVER was able to link the incoming data to the expected descriptions from the domain ontology according to the rules and constraints defined for various phases and situations. The tables below show the simulated output from SAVER for each scenario. Situation awareness level 1 (SA1) in column 3, the comprehension of situation (SA2) in column 4, and the prediction (SA3) in column 5, are according to the SA requirements.

##### 4.5.2.1 Scenario 1

**Table 4.6 SAVER's output from scenario 1 (Javed & Norris, 2011)**

Scenario Number	Emergency Phase	SA1: Magnitude (M) Depth (D) Location (L)	SA2	SA3
1	Pre-confirmation	M = 8.1 D = 60 km L = 15N-115W	High Magnitude  Location is in water	Can generate tsunami!
1	Tsunami confirmation Pre-decision	DART data from sensor near source	Wave height is very high near source  Tsunami is generated	Potential tsunami threat!
1	Evacuation decision	DART data from all sensor until now	Wave height is very high on all active sensors	Impact time:13hrs North-east of New Zealand

In Scenario 1, an earthquake of magnitude 8.1 is high enough to generate a tsunami and this magnitude data is simply classified as Level 1 SA data as it is a relevant piece of information for the understanding the situation. For SA Level 2, the magnitude data is interpreted as high enough to generate a tsunami. Similarly, data about the co-ordinates of the earthquake is also regarded as SA Level 1 since it is relevant to situation assessment in the current scenario, and SA Level 2 assessment interprets the co-

ordinates as an offshore or onshore location (offshore in this case). This information is combined using rules to generate Level 3 SA indicating that since the earthquake is high enough to generate a tsunami and the source is located offshore, it is likely to generate a tsunami. Therefore, SAVER's suggestions on the first stage are accurate and promising.

In the second stage of Scenario 1, data from the DART sensor close to the earthquake source confirms that there is a change in wave characteristics like height, amplitude etc., and this information qualifies as Level 1 SA since it is relevant to the understanding of the prevailing situation. This change in the wave information is interpreted as a tsunami generation and therefore tsunami generation is confirmed to provide Level 2 SA. Once, tsunami generation is confirmed, SAVER predicts a threat to the coastal areas as a Level 3 SA.

In the third stage of Scenario 1, data (SA Level 1) from DART sensors in the ocean shows how waves are propagating, i.e. direction and wave heights at different sensor locations that lead to an understanding of situations at those sensor locations providing Level 2 SA. This Level 2 SA, along with the knowledge of previous similar scenarios, becomes the basis for SA Level 3 SA to predict the expected arrival time of waves, height of largest waves and expected inundated areas.

#### 4.5.2.2 Scenario 2

**Table 4.7 SAVER's output from Scenario 2 (Javed & Norris, 2011)**

Scenario Number	Emergency Phase	SA1: Magnitude (M) Depth (D) Location (L)	SA2	SA3
2	Pre-confirmation	M = 6.8 D = 125 km L = 28S-107W	Moderate Magnitude  Location is in water	Can generate tsunami!
2	Tsunami confirmation Pre-decision	DART data from sensor near source	Wave height is very high near source  Tsunami is generated	Potential tsunami threat!
2	Evacuation decision	DART data from all sensor until now	Wave height is very high on all active sensors	Impact time:11hrs North-east of New Zealand

In Scenario 2, earthquake magnitude data is Level 1 SA and once compared with rules, it generates SA Level 2 information i.e. earthquake magnitude is high and enough to generate a tsunami. Similarly, the source location co-ordinates of the earthquake comprise Level 1 SA data, which is transformed to Level 2 SA information that these co-ordinates point to an offshore location. Hence, all this information is combined and compared with rules to generate overall SA Level 3 information that the earthquake is of high magnitude and its source is located offshore and therefore it is able to generate a tsunami. Moreover, at the next stage of scenario simulation, DART data from the sensor closer to the earthquake source shows that there is a change in attributes of waves, therefore this change is interpreted as a tsunami to provide Level 2 SA. The confirmation of tsunami generation predicts the threat to the nearby coastal areas representing Level 3 SA information.

At the third stage of Scenario 2, data (level 1 SA) from DART sensors in the ocean shows a summary of the direction and height of waves at different sensor locations. The wave data is used to provide Level 2 SA i.e. understanding of the behaviour and propagation of waves at different sensor locations. To generate Level 3 SA, i.e. expected arrival time of waves, height of largest waves and expected inundated area, at different coastal areas information from Level 2 SA about direction of propagation, amplitude etc. is used along with the knowledge of previous similar scenarios.

#### 4.5.2.3 Scenario 3

**Table 4.8 SAVER's output from Scenario 3 (Javed & Norris, 2011)**

Scenario Number	Emergency Phase	SA1: Magnitude (M) Depth (D) Location (L)	SA2	SA3
3	Pre-confirmation	M = 3.9 D = 78 km L = 4N-171W	Low Magnitude  Location is in water	Cannot generate tsunami!
3	Tsunami confirmation Pre-decision	DART data from sensor near source	Wave height is normal near source	No tsunami threat!
3	Evacuation decision	DART data from all sensor until now	Wave height is normal on all active sensors	No impact, no threat!

In Scenario 3, earthquake attributes, i.e. magnitude, source location and depth are relevant to understand the tsunami situation (Level 1 SA data). The attributes perceived

in level 1 SA are compared using rules to generate SA Level 2 information i.e. earthquake magnitude is low and insufficient to generate a tsunami. Similarly, source location co-ordinates of earthquake are Level 1 SA data, which is transformed to level 2 SA information indicating that these co-ordinates point to an offshore location. All of this information is combined and compared with rules to generate overall SA Level 3 information i.e. although the earthquake source is located offshore; it has too low a magnitude to generate a tsunami.

Moreover, on the next stage of scenario simulation, DART data from the earthquake regions is still collected from the closest sensor to make sure that the tsunami is not generated declaring wave height is normal to present Level 2 SA. Therefore, no change in the DART data from the closest sensor infers that a tsunami has not been generated and so the Level 3 SA infers that there is no tsunami threat in the near future.

At the third stage of Scenario 3, data (SA Level 1) from all the DART sensors in the ocean provides a summary of wave attributes. Since no change in the behaviour of waves is observed, these DART sensors will remain inactive. This absence of activity is seen as no tsunami generation (level 2 SA) and therefore no possible threat (level 3 SA).

#### 4.5.2.4 Scenario 4

**Table 4.9 SAVER's output from Scenario 4 (Javed & Norris, 2011)**

Scenario Number	Emergency Phase	SA1: Magnitude (M) Depth (D) Location (L)	SA2	SA3
4	Pre-confirmation	M = 7.9 D = 60 km L = 21S-64W	High Magnitude  Location is on land	Cannot generate tsunami!
4	Tsunami confirmation Pre-decision	DART data from sensor near source	Wave height is normal near source	No tsunami threat!
4	Evacuation decision	DART data from all sensor until now	Wave height is normal on all active sensors	No impact, no threat!

In Scenario 4, incoming earthquake information is classified as Level 1 SA to give a summary of earthquake attributes i.e. magnitude, source location, and depth. These perceived attributes are compared using rules to develop Level 2 SA information i.e.

earthquake magnitude is high enough to generate a tsunami. In addition, the source location co-ordinates of earthquake (Level 1 SA data) are interpreted to develop Level 2 SA information that these co-ordinates point to an onshore location. Therefore, once this information is combined and compared using the rules, Level 3 SA is generated showing that the earthquake is located onshore, even though its magnitude is high; it cannot generate a tsunami.

On the second stage of scenario simulation, DART data from the earthquake regions is still collected from the closest sensor to make sure that a tsunami is not generated. In the current scenario, SAVER provides Level 2 SA that wave height is normal and no change in the DART data from the closest sensor infers that the tsunami has not been generated. Hence, at Level 3 SA, SAVER infers that there is no tsunami threat in the near future from the earthquake under consideration.

At the third stage of Scenario 4, data from all the DART sensors in the ocean provides a summary of wave attributes in the form of Level 1 SA. Like Scenario 3, since no change in the behaviour of waves is observed, these DART sensors remain inactive. This absence of activity is interpreted as no tsunami generation (Level 2 SA) by SAVER and therefore it is inferred that there is no possible tsunami threat (Level 3 SA).

In all the scenarios described above, SAVER has responded very well and as expected. It has successfully generated meaningful and useful interpretations of the incoming data. These interpretations are according to SA requirements and seem very promising to improve the decision making ability of emergency managers. More insight into the evaluation will be gained by the user evaluations in its actual use and are covered in the following chapters.

SAVER has effectively modelled situation information on two levels - 1) domain knowledge to infer what type of information is required to gain various levels of SA by considering the SA requirements, and, 2) transforming the actual information that is needed to achieve all levels of SA. Therefore, it has not only fruitfully classified incoming information but also provided accurate inferences. Since inference uses rules, these rules offer a reason for every classification or suggestion so that a user can understand how SAVER has reached its conclusions.

## 4.6 Conclusions

Considering the importance of SA requirements and the complexity involved in gathering these requirements, the cognitive task analysis tool, EDGIA, is used for information elicitation. Information required for developing and maintaining SA in relation to the goals, tasks and decision making needs of five emergency manager roles were elicited according to three levels of SA. The EDGIA method was quite successful as very few changes were recommended during validation of these requirements by a nationwide questionnaire. The validation process hence showed that this research has accurately identified the comprehensive information needs of emergency managers. In comparison to previous studies, this is the first known occasion that comprehensive information requirements of various Group Emergency Operation Centre (GEOC) roles are gathered for a tsunami scenario. These SA requirements became the basis for the design and development of a system to support a computer based SA.

Ontology was proposed as a solution to model a dynamic situation because of its various applications in the field of semantic tagging of incoming information. This can be useful for the design of a computer based agent that can automatically perform information processing and fusion to give it a meaningful and useful form. Ontology was successfully used to design a computer based prototype dubbed SAVER that can model an emergency situation, apply rules and constraints to input data and their relationships, draw correct inferences from the assembled information and predict future situation states.

The developed SAVER was evaluated to see whether the situation modelling was accurate and the inferences made are useful and aligned with the SA requirements. SAVER is tested in four simulated scenarios to see its output for the SA requirements at three different levels of SA. Results demonstrate that an ontology based inference can be used to construct systems that can support and potentially improve human situation awareness during emergency decision making. Moreover, all the rules were fired as required and accurate inferences were made as per the situation and SA requirement. Therefore, it was deduced that such systems can be tested in simulated experiments by human evaluators.

SAVER provides situation assessment and shares the results with human decision makers, so they can get another view of the situation and critically review their situation

model, whilst saving valuable time during crisis management. Moreover, it can become the basis to develop an automatic information processing and fusion system. Such a system can help in making better decisions quickly that will reduce disruption, economic cost, and most importantly, loss of life.

# Chapter 5

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## IMPROVING AN INDIVIDUAL'S SITUATION AWARENESS USING SAVER

### 5.1 Introduction

This chapter tackles the problem of supporting the individual's Situation Awareness (SA) identified in Chapter 3. The problem is first explained in detail. In the next section, the suggested solutions to the problem are discussed. The chapter then explains the proposed design and development of the solution prototype. The design and development section is followed by the evaluation section. In the last section of the chapter, results are summarised and conclusions provided.

### 5.2 Problem Identification

In emergency management, to achieve a goal certain tasks are performed, each of which requires a certain level of SA for successful completion. An individual's SA in an emergency situation is affected by many cognitive factors like short term memory, long term memory, stress level, mental models etc. (Bolstad & Endsley, 2000). These factors are highly dependent on the individual's level of experience and affect SA at different levels (Endsley, 1995b). Getting the wrong perception of the situation elements can lead to the wrong decisions or mistakes in carrying out the tasks and hence endangering the whole operation. This is because the perception becomes the basis for the comprehension and projection of the situation and therefore it needs to be accurate to gain a correct understanding of the situation. In addition, mistakes can be made on the comprehension level too, i.e. while developing an understanding of the situation elements, and these mistakes can also lead to the wrong projection or predictions about the situation and can ultimately result in wrong decisions. Therefore, developing and maintaining accurate SA at every level is critical and important for the success of an operation. Moreover, as mental models are linked with the experience and usually highly experienced emergency managers are scarce in emergency situations, there is a high risk of misunderstanding the situation by novice emergency managers. Even

experienced emergency managers are prone to mistakes when the stress level is high and time to process the information is short.

Furthermore, stress is a conspicuous feature of emergency situations, along with multiple responsibilities, shortage of available time and fatigue takes over the already meagre short term memory where all the information processing is done. Hence, either it takes too long to understand the incoming information or, there is a high chance of missing some important information while performing a task or making a decision. Because of the workload and multiple roles, an operator's comprehension of a state may concentrate on a specific view of information and ignore other important aspects. The negative impacts of some of these factors can be minimised to improve SA by automating repetitive tasks using a computer based systems so that these tasks are less attention demanding and the workload of operators is reduced. A system with static user requirements cannot work, as there are many different users with dynamic requirements. However, having multiple systems will create problems of integration and inter-operability. Therefore, the problem is how to design a computer based system that provides support to an individuals' SA, meeting their diverse and dynamic requirements.

In emergency operations, while making sense of situations, emergency managers very often consult domain experts or other team members to get their point of view on the prevailing situation. This helps them to clarify their doubts (if any) in their own mental model or problem and to update their SA about the situation. Similarly, we believe that a computer based system, which has the perceptions of situation elements and semantically understands their meaning/significance, can be very helpful in updating human SA. This chapter describes the evaluation of such a system to understand the extent of improvement it can bring to the human SA.

Since SA is affected by the way in which information is presented to the user, the HCI of such a system can play an important role, e.g. by attracting the user's attention by the use of flashing colours, bold text or pictorial information like a graph, map or picture etc. Therefore, it is important to understand the best way to present information to the users so that their SA can be enhanced to the maximum possible extent.

Below is a summary of the problems discussed above in the form of questions:

1. How to design a computer based system supporting an SA by fulfilling diverse user requirements and keeping the information load to a minimum?
2. Whether SAVER (the prototype developed in Chapter 4) can improve SA during a mass evacuation operation?
3. How to design a user interface design for SAVER (the prototype developed in Chapter 4)?
4. How to evaluate the user interface design developed for SAVER (the prototype developed in Chapter 4)?

### **5.3 Suggested Solution to the Problem**

In Endsley's model of SA, an individual's SA requirements are defined as the dynamic information needs associated with the goals of operators (Endsley et al., 2003b; Wickens, 2008; Endsley, 2000). The information presented to a person through a system without understanding the effect of his/her goals on his/her SA has no meaning (Endsley et al., 2003b). Therefore, the capability of an information system to support emergency managers and decision makers in successfully accomplishing their tasks and making accurate decisions depends on how well the system supports the attainment of their goals (Albers, 2004). Hence, supporting their SA will mean providing them with the information they need to carry out their tasks to achieve their goals.

The information requirements of different roles needed to develop and maintain their SA during various phases of mass evacuation operation have been gathered and reported in Chapter 4. These information requirements are the basis of the system design. To provide specific and readily useable information, SAVER should consider its users' contextual parameters, i.e. his/her role, responsibilities, goals and objectives, tasks, and more importantly, the information required to develop and maintain his/her SA to carry out these tasks. Hence, in other words SAVER should provide the right information to the right persons at the right time to achieve their goal. This can be achieved by the semantic modelling of the contextual information (Chen, 2004).

By reminding the decision makers about the information they may have overlooked, selectively presenting information of immediate relevance to their roles and requirements, and advising on the best possible course of action, can highly improve their decision making effectiveness and efficiency. Hence, the suggestion is to leverage

the effective and efficient emergency decision making by improving the SA of emergency managers. Moreover, the domain knowledge about the context of its users can be ontologically modelled to enable semantically enriched information integration and presentation. Therefore, the system with an understanding of the situation can work as a team member of emergency managers to update their SA, instead of simply a computer system.

Since SAVER is intended for human use, a module of SAVER needs to be developed which has user interfaces for use in emergency scenario simulations. These interfaces should allow users to test and evaluate various SAVER features. Hence, the main objective of this chapter of the thesis is to provide an adequate user interface to the proactive information about the situation on all three SA levels. System should promote a more holistic view of a situation to enhance SA and to prompt its users with the additional information related to their current goals.

SA oriented system design (Endsley et al., 2003), which is a User Centred Design (UCD) approach is considered for designing the user interface since it aims at improving the SA.

## **5.4 Design and Development**

There are two major belief systems in Human Factors (HFs) related to the design of systems: the technology centred approach and the user centred approach (Endsley et al., 2003). Traditionally, systems have been designed from a technology centred perspective. Alternatively, the user centred design (UCD) is a better mode of achieving more effective systems (Endsley et al., 2003). Following the UCD approach, an SA oriented system design focuses on the users' needs for the development of an information system that supports and improves users' SA so they can make good decisions. "Supporting user's SA" is different in different domains (Endsley et al., 2003). It can be achieved by fulfilling the users' dynamic information needs in that particular domain (Endsley et al., 2003).

Situation Awareness (SA) can answer the questions of what information is needed, how to maximise the performance of decision makers, what information means in a particular context etc. (Endsley & Rodgers, 1998; Prasanna et. al., 2009). SAVER provides three levels of SA and helps in the decision making process by suggesting the possible interpretation of the situation along with the reasons for recommending them.

The operation of SAVER will have a twofold benefit. If the decision maker agrees with the situation analysis suggested by the system, then this will increase the manager's confidence in his SA and reduce delays whereas a difference between the human and machine recommendation will alert the managers to the aspects of a situation that he/she might have missed. Therefore, the objective of this chapter is to meet the dynamic needs of users, by providing them with highly specific and usable information.

#### **5.4.1 Contextual SA information**

Chen et al., (2004) defines context as:

*“Context is information about a location, its environment attributes (e.g. noise level, light intensity, temperature and motion) and the people, devices, objects and software agents that it contains. Context may also include system capabilities; services offered and sought the activities and tasks in which people and computing entities are engaged, and their situational roles, beliefs and intentions”.*

Therefore, according to the above definition, context information about the people, and their tasks, activities and situational roles can be used to distinguish them from the other users. Moreover, the same attributes can be used to provide the exact information required by these people. Hence, the systems using the context information to provide services are called context aware systems. Following are the relevant possible applications of the context aware system in the current research project.

##### ***5.4.1.1 Possible applications of context information in SAVER design***

###### **a. Personalised user interface**

In the past, context information has mostly been used for user interface design in mobile devices (Schilit, 1995; Schilit et al., 1994; Rekimoto, 1996). More recently, many web based applications have also started using context information for interface design to meet the user needs in the best way. Some web applications, e.g. Google Inc. use many context parameters, the most important of these are location, tasks (email context, browsing or searching context) and a user's behaviour patterns from previous usage (historical data).

Similarly, in SAVER, context information is being used to provide the right information to the right person in the right way. Hence, the user interfaces can be optimised according to the user roles and tasks they are performing, for example, interface for a Planning and Intelligence role to develop a situation report or incident plan, interface

for a Controller to have an overall look on the operation or summary of areas whose evacuation has been completed or the remaining areas on a map etc.

### **b. Adaptive behaviour**

*Content adaptability:* Context information can be used to generate an adaptive behaviour for the user depending upon various factors. Using the location, role and position parameters of context, emergency managers in Group Emergency Operation Centres (GEOC) will get different levels of information than managers in the Emergency Operation Centre (EOC) as GEOC looks after several EOCs. Similarly, the National Crisis Management Centre (NCMC) which looks after GEOCs from all over New Zealand do not require great detail of what is going on in the individual cities or suburbs but require only a summary of the whole situation. Hence, various context parameters are combined to generate the different sets of users and provide an adaptive situation analysis for them as per their requirements. Similarly, the content can be adapted according to the properties and capabilities of the devices used by emergency managers.

*Content re-usability:* Moreover, content developed for one purpose can be adapted and re-used for another purpose, e.g. incoming information to update situation awareness can be directly added in the situation report along with the situation interpretation saving a lot of time for the planning and intelligence role.

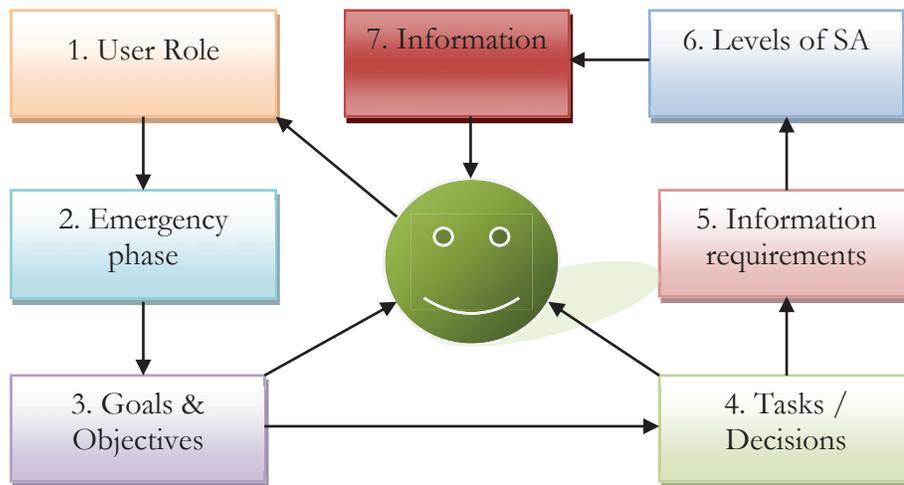
### **c. Intelligent applications**

Context can also be used to develop an intelligent application to facilitate the users by automating various processes for them. The automation reduces their workload and stress, both of which are the biggest challenges for emergency managers in emergency situations. For example, the contextual information about the job roles, their goals, and objectives can be used along with the SA requirements to develop information that will fulfil most of the requirements of SA development and maintenance.

#### ***5.4.1.2 Acquiring context specific information***

SAVER uses context information combined with SA requirements to fulfil the contextualised SA requirements. Therefore, information processing can be automated according to the SA requirements of the emergency managers using their contextual information of roles, objectives, tasks and location etc., Moreover, SAVER also uses the contextual information for adaptive user interface and adaptive content generation as discussed above. Figure 5.1 below shows how various context parameters can be used

by the following general steps to provide the specific information to the users in a personalised form.



**Figure 5.1 Personalised information for users using contextual information**

In Figure 5.1 above, user context is acquired using inference over the following different clues.

1. Identify user's role
2. Check the emergency phase
3. Check user's goals and objectives according to the user's role and the emergency phase
4. Infer the tasks and decisions that user needs to make to achieve their goals and objectives
5. Gather the information requirements of the user to carry out these tasks and make decisions
6. Categorize the information according to the three levels of SA
7. Provide the information to the user

Acquiring the accurate context is a great challenge in context aware systems. Moreover, developing software tools to process the sensed contextual information is also an important issue (Abowd, et al., 1997; Benerecetti et al., 2001; Schilit et al., 1994). Therefore, this research also addresses the issues of modelling, inferring and using of context information to provide personalised information to emergency managers.

## **5.4.2 Ontology based inference for contextual SA information**

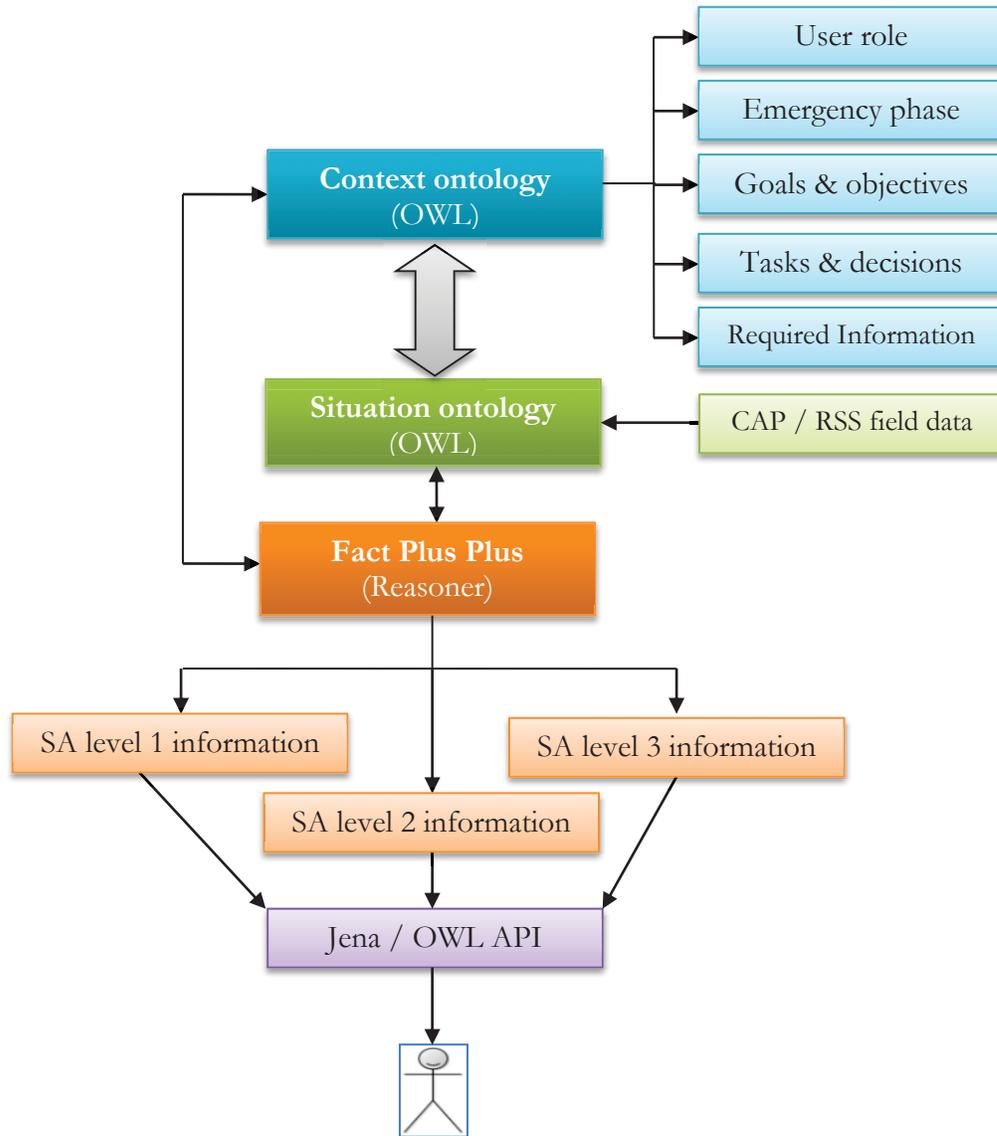
### ***5.4.2.1 Context reasoning***

Context reasoning is a method of processing the context information and making sense of it, i.e. making the context information useable in context aware systems. Context reasoning also detects and resolves inconsistent information about context. In context aware systems, the context of the system is automatically decided by using the context clues or information. To enable automatic processing of context information, it must be presented in machine processable form. Previously, (Asthana et al., 1994; Coen, 1998; Dey, 2000; Schilit et al., 1994) contextual information has been presented using data structures or class objects in programming languages.

However, since these languages only provide syntax representation, they lack semantic representation and hence inter-operability which is considered essential for information sharing (Chen, 2004). Recently, Chen (2004) proposed an ontological rule based logical inference architecture called CoBrA to enable context reasoning. Web ontology language (OWL) is a perfect fit for presenting context information since it is flexible enough to model context information in a formal language (machine processable) and also allows rule based inference. Another important reason for choosing an ontology based approach for context reasoning is that this research is already using ontology based situation modelling and reasoning (Chapter 4). Therefore, both context and situation modelling and reasoning can have a seamless interface. One of the advantages of this approach is the flexibility for extension. For example, it would be very easy in future to add more dimensions of context information like types of devices (desktop computers, smart phones, Personal Digital Assistants, computer tablets etc.) used by users to provide personalised information according to the device features (Christopoulou & Kameas, 2005; Ye et al., 2007).

### ***5.4.2.2 Architecture design for using context information***

Below is the architecture design of SAVER using ontological contextual and situation reasoning.



**Figure 5.2 SAVER architecture design for personalised information**

In Figure 5.2 above, SAVER detects the user login and provides this information to the context ontology. The reasoner checks whether there is any prevailing emergency situation from the activities log, i.e. activities performed by emergency managers from the time when an earthquake occurred to the current time and infers the current state of the emergency situation. However, the user can also manually update the emergency phase status in the SAVER. The stepwise process of an automatic emergency phase change is as follows. Each sub-class of Time has a data property “*currentStatus*” which can have a Boolean value, i.e. true or false. Only one phase can have “true” as *currentStatus* and status can only be changed in sequence, i.e. from “pre-confirmation

phase” to “tsunami confirmed decision phase” and so on. Table 5.1 below summarises various emergency phases and the status of *currentStatus* data property associated with it.

**Table 5.1 Boolean representation of various emergency phases**

Situation	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Situation normal	F	F	F	F	F
Pre-confirmation phase	<b>T</b>	F	F	F	F
Tsunami confirmed decision phase	F	<b>T</b>	F	F	F
Evacuation phase	F	F	<b>T</b>	F	F
Post evacuation phase	F	F	F	<b>T</b>	F
Return phase	F	F	F	F	<b>T</b>

Depending on the emergency phase information, goals and objectives are obtained from the context ontology and related tasks are advised to the user. SAVER not only reminds the user about his/her tasks and decisions but also provides the information required to perform the tasks and make decisions. This task/decision information is also provided as a supplement to the situation analysis (Chapter 4) done by SAVER. Hence, the user gets the pre-processed information on different levels of SA according to the requirement. Other parts of the architecture design have been described in the “architecture design” section of Chapter 4.

#### ***5.4.2.3 Ontologies developed for contextual SA***

In this module, previously developed situation ontologies are extended to accommodate the contextual information. Figure 5.3 below shows an example of the partial ontology using contextual concepts (*Goals, Tasks, Role, EmergencyPhase* etc.) and their relationships (*toAchieve, make, during, hasGoal*, etc.).

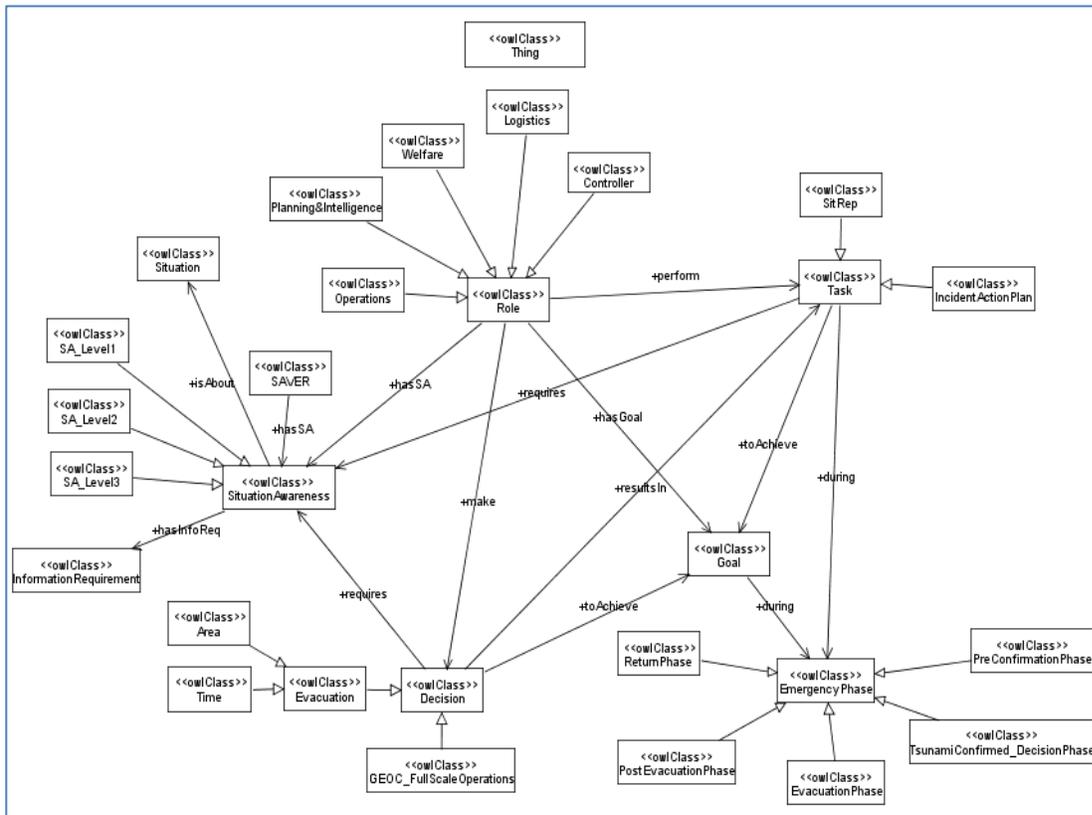


Figure 5.3 Partial ontology using contextual concepts

Figure 5.4 below shows the information requirements according to the various emergency phases and roles.

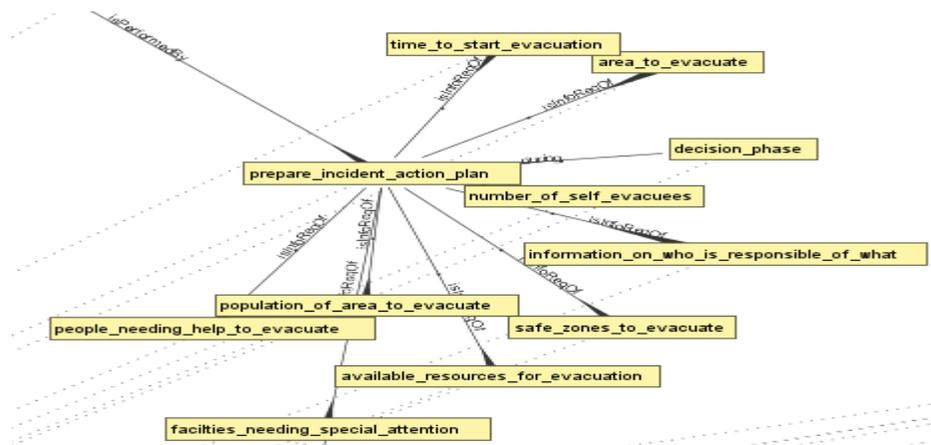


Figure 5.4 Partial ontology showing information requirements according to the various emergency phases and roles

Figure 5.4 above shows that the task e.g. *prepare\_incident\_action\_plan* during the emergency phase *decision\_phase* has information requirements like *number\_of\_self\_evacuees*,

*population\_of\_area\_to\_evacuate, available\_resources\_for\_evacuation, safe\_zones\_to\_evacuate. information\_on\_who\_is\_responsible\_for\_what* etc.

### **5.4.3 Human computer interaction (HCI) design**

#### ***5.4.3.1 Information presentation***

Apart from information needs of decision makers, SA requirements also focus on how information is integrated to tackle each decision (Endsley et al., 2003). During time critical and complex situations such as emergencies, the way in which information is presented to users influences their SA. Effective and efficient decision making depends on how accurately and efficiently the needed SA is developed, therefore, to speed up the situation assessment process, duration to acquire the needed information can be reduced (Endsley et al., 2003). Just presenting a mass of data will do no good and confuse the user who has limited time to process it and make use of it. Therefore, providing processed and readily usable information for a user's SA also contributes to enhance their SA.

#### ***5.4.3.2 Situation awareness oriented design principles***

SA oriented design (SAOD) approach (Endsley et al., 2003) is used to design the user interface. Endsley et al. (2003a) proposed 50 design principles for systems that aim to enhance SA and, more recently, (Bolstad et al., 2006) has prioritized eight of them as critical for good situation awareness. Briefly, (see the Bolstad et al. paper for details) the eight main principles are as follows:

1. Organizing the information around goals: Displays and interfaces should present the information needed to support the decision making to achieve a particular goal.
2. Present Level 2 SA information directly: Support the comprehension by displaying information that is processed and integrated in SA terms. Reduce the need for users to process information.
3. Provide assistance for Level 3 SA: Support decision making with systems that are capable of projecting the future events and states of the current situation.
4. Support global SA: Design displays that deliver the big picture (e.g. an overall map visible at all times) and minimise attention narrowing.

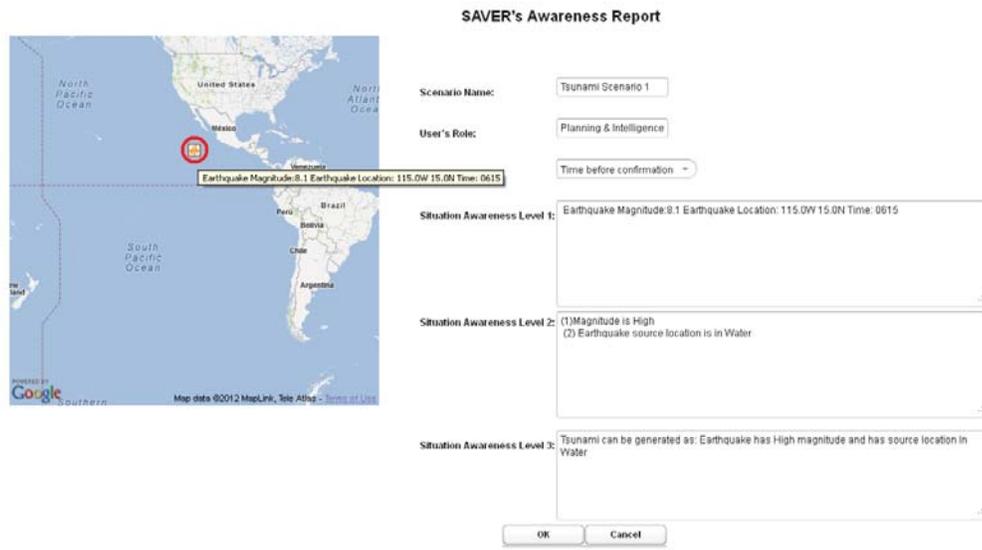
5. Support trade-offs between goal driven and data driven processing: A balance between goal driven and data driven system design is required so that both can complement each other.
6. Keep the user focused on important attributes: This makes it easier for a user to bring their accumulated experience to bear on a situation and to amplify their awareness (Kaplan & Simon, 1990).
7. Take advantage of parallel processing: Parallel systems can save time by processing multiple information streams and validation checks concurrently.
8. Use information filtering carefully: Filter information to reduce overload but impose appropriate criteria to avoid removal of key material.

These principles have been developed on the basis of theoretical models and processes involved in acquiring and maintaining SA in dynamic and complex environments (Endsley, 1990). Moreover, SA oriented design principles are applicable to a wide variety of system designs. They have been successfully applied as a design philosophy for systems involving remote maintenance operations, medical systems and flexible manufacturing cells (Endsley, 2001). Therefore, since current research also aims at improving the SA of emergency managers for decision making during mass evacuation operations, these principles are being used to design the user interface of SAVER.

#### **5.4.4 SAVER features**

A prototype user interface of the SAVER system was developed to see if the information provided by SAVER improved the SA of emergency managers at all SA levels. Moreover, it was developed to evaluate the human interaction (HCI) and functionality of SAVER. The SA requirements identified in section 4.4.1 indicate the information required to enhance various levels of SA for diverse job roles at different phases of an emergency. Therefore, interfaces to support all three SA levels were developed for evaluation. For Level 1 SA, an interface was developed to provide perception of information elements that were relevant and required for a particular job role and emergency phase. For example, Figure 5.5 shows how the interface displayed the Level 1 SA information for Planning and Intelligence Managers at the “pre-confirmation” phase of a tsunami scenario. The information about the earthquake magnitude, source location, depth etc. was provided to represent Level 1 SA at a pre-confirmation phase of a tsunami. The same information summary, i.e. magnitude,

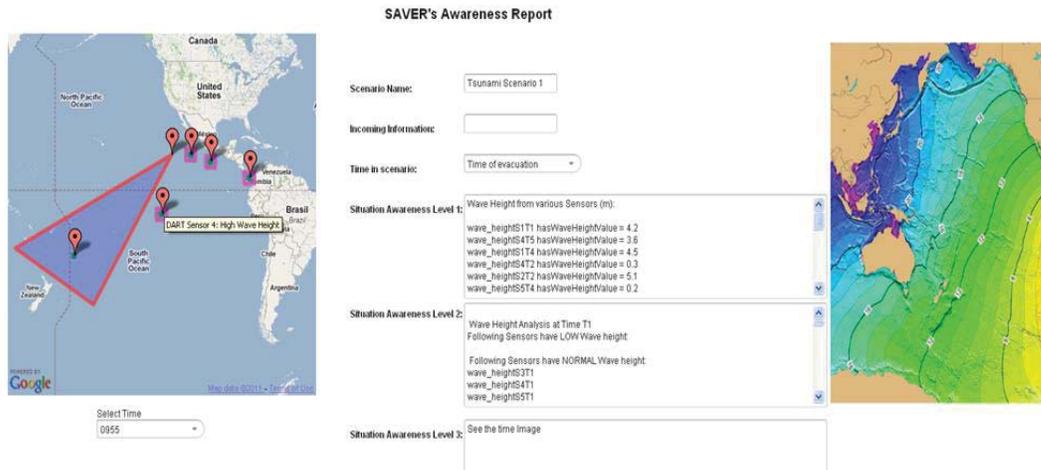
location and depth was also shown on the map if the cursor hovered over the icon indicating the earthquake.



**Figure 5.5 Interface showing levels of SA information about earthquake attributes**

In Figure 5.5, the red or green colour of the circle around the earthquake location specifies whether the earthquake magnitude is of high or low intensity respectively. This interpretation of situation elements represents Level 2 SA information. Furthermore, by showing the location on the map apart from textual information also makes clear whether the earthquake source is located on/offshore.

Details of wave heights from DART data were provided in text format and the same wave attributes were displayed as a Level 1 SA if the cursor was placed on the sensor icon as shown in Figure 5.6 below. Moreover, the circle around the sensor icon provides Level 2 SA by indicating whether the wave height at this sensor is very high, high, medium, or low using red, pink, blue and green colours respectively. Moving the cursor on these circles also displayed a “tool tip” note that “wave height is HIGH” if the circle was pink as shown in Figure 5.6 below. For Level 3 SA, the predicted time of arrival of the wave along with the expected height was provided to managers so they could start preparations and planning for the probable evacuation while detailed inundation models were developed. The coloured picture on the right side provides the expected arrival time of the waves at different coastal areas from various tsunami sources in the Pacific Ocean to give an idea of the number of hours available for evacuation.



**Figure 5.6 Interface showing three levels of SA information about wave information**

Moreover, Level 2 SA was provided to show the meaning of perceived information in the prevailing situation (see Figure 5.6 above) with colour circles around the sensor icons. This interpretation also explained the significance of perceived information in relation to goals and objectives of the job role (user). Likewise, in Figure 5.7 below, the blue circle with blue fill indicates the current position of propagating waves based on DART data.

Similarly, Level 3 SA information was provided in the form of a prediction about the future states of a situation or possible evolution from the current situation. For example, in Figure 5.7 below, the pink area indicates the areas under tsunami risk and when a user puts a cursor on the border of this area, expected arrival time of the tsunami waves is shown.



**Figure 5.7 Providing comprehension and projection about the evolving situation**

The designed system focuses on the information requirements of emergency managers and the flow of information during the emergencies. As time passes, new information is added to the existing situation model in a meaningful way to create an expressive and useful overall picture of a situation. Hence, this recognition of a situation by SAVER can be used in many different ways, e.g.

- Updating the human SA
- Automatically triggering other processes like planning for mass evacuation, and,
- Informing various job roles about their tasks and responsibilities depending upon the prevailing situation

Having a true understanding of the situation allows SAVER to support its human users by providing them with a reasoned explanation of the situation. This will help human decision makers to think critically about their mental models and improve their decision making capability. In addition, semantic understanding of an emergency situation and its phases permits SAVER to guide emergency managers about their responsibilities in a prevailing situation along with the information required for decisions. This process improves the efficiency of the task performance of individuals by supporting their SA and saves emergency managers time for other important tasks.

## **5.5 Evaluation**

Supporting human users in intensively complex environments through interface design is a growing challenge for human factors (Kirlik and Strauss, 2006). Having many dimensions, SA depends on the environment and the task. Advancement in the technologies supporting SA depends on the advancement in SA measurement techniques (Salas et al., 1995). SA measurement techniques are classified into two basic categories:

- Direct measurement of SA, i.e. objective real time investigations
- Indirect measurement of SA by inferring a user's SA based on the user's functional state, behaviour, performance or subjective questionnaires.

Our approach to assessing individual SA focusses on both direct and indirect approaches to evaluate SAVER by all possible means. Moreover, SAVER is also evaluated according to the human computer interaction (HCI) techniques. Objective measures of SA have been extensively validated to be reliable for various domains

(Fracker, 1988; Gugerty, 1997; Endsley and Rodgers, 1998). In using objective measures, an individual's perception (Level 1 SA), comprehension (Level 2 SA) and projection (Level 3 SA) of the situation are compared with some ground truth of the situation. Therefore, data is collected by asking the participants about the environment, answers are then compared with the reality of the situation to see the number of correct answers. Three ways to gather objective measurement data are (Saner et al., 2009):

- In real time, as task is being completed
- During an interruption in the task activity
- After the task is completed

The best example of this approach is Situation Awareness Global Assessment Technique (SAGAT) (Endsley, 2000). SAGAT can be used to measure SA on all three levels (Endsley, 1995a). This type of measurement directly taps into the operator's perception rather than inferring them from their behaviour, which may be affected by other factors (Endsley, 2000). Therefore, this research uses SAGAT for the direct measurement of SA as it is the most widely used and accepted SA measurement technique.

### **5.5.1 Direct measurement of SA using SAGAT**

#### ***5.5.1.1 Situation Awareness Global Assessment Technique (SAGAT)***

The Situation Awareness Global Assessment Technique (SAGAT) is a tool developed to assess a user's SA across all the elements of SA requirements (Endsley, 1988b, 1990). In a simulation, the system of interest is frozen at randomly selected times, system displays are blanked and users are asked about their perceptions of the situation at that time. SAGAT queries can be tailored to evaluate the user's SA on all three levels of SA. Detailed information about a user's SA is collected on an element basis and evaluated against reality, thus proving an objective assessment of the user's SA.

Queries across the full range of a user's SA requirements, minimise the possible biasing of attention, as subjects cannot prepare for the queries in advance since they could be queried over almost every aspect of the situation to which they would normally attend. Moreover, these queries are phrased to be as similar as possible to how the person thinks about the information, and should not require any extra transformations or decisions on the part of the user (Endsley, 2000).

### ***5.5.1.2 Validity of SAGAT***

The SAGAT technique has shown a high degree of validity, sensitivity and reliability for measuring SA (Endsley, 2000). SAGAT also has good sensitivity to the system manipulations, automation manipulations, expertise difference and operational concepts in a variety of domains (Vidulich, 2000). Moreover, findings indicate that SAGAT is sensitive to the changes in the task load and to the factors that affect the user's attention (Endsley & Rodgers, 1998; Fracker, 1988; Gugerty, 1997). In addition, the reliability of SAGAT is also demonstrated by many studies (Collier & Folleso, 1995; Endsley & Bolstad, 1994; Fracker, 1991; Gugerty, 1997).

### ***5.5.1.3 SA Measurement***

In order to measure the SA using the method discussed above, 16 members of the New Zealand Group Emergency Operations Centre (GEOC) participated in two types of experiments, i.e. using SAVER and without using SAVER. The overall method of the experiment is the same as SAGAT (Endsley, 2000). Analyses of SA requirements (at all three levels of SA) were used to develop 17 questions, which were asked during four different freezes. A stress factor was introduced by showing the timer with every question. Details of queries used are provided in Appendix G. A web based application for questionnaires is used to gather responses since it can reduce the burden of analysis. Moreover, users do not have to leave the computer screen, which can result in forgetting the SA elements being queried. In addition, using a computerised questionnaire allowed the use of a virtual ticking clock along with every question to create the stress factor and to capture the duration of answering each question.

Duration of response to every question is timed for comparison, as time is also an important factor during emergency decision making. To avoid any bias that can affect the results, experiments were done in two parts on two different days, which were more than a week apart so that the learning from one experiment did not affect the next session.

### ***5.5.1.4 Participants***

All the participants (n=16) were real emergency managers and active member of EOCs with two to eight years of practical experience and all of them had participated in either a real event or in a national exercise. Details are provided in table 5.2 below. All of them were familiar with the various roles of EOC and their responsibilities.

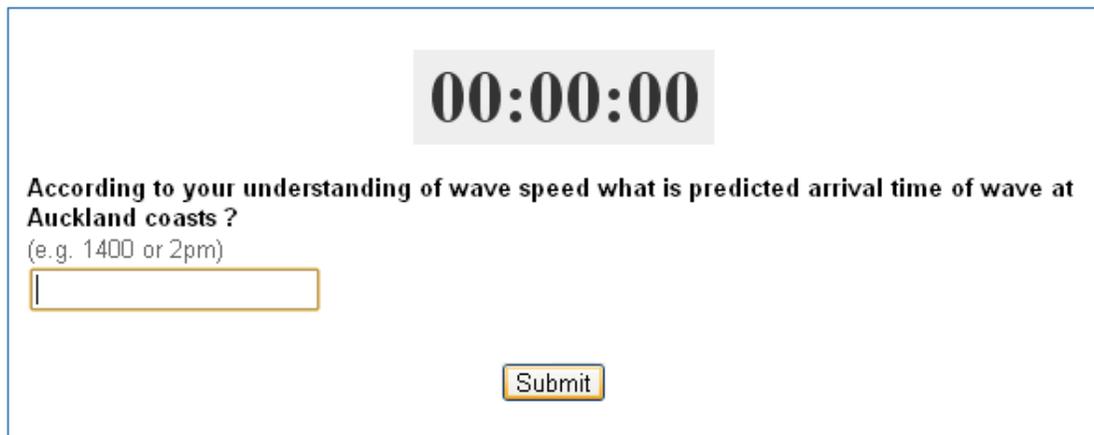
All the participants performed the experimental tasks. Since, SA was measured on three levels for diagnostic analysis; the results of each SA level were combined to see the overall SA at three levels. Later, overall results of each level were combined to generate one SA measure of each individual. The user's score was analysed as the percentage of correct answers against the ground truth. Individuals were coded according to their experiment type, and whether he/she performed the experiment with SAVER first or not. For example, the code P1S1 was assigned to participant P1 if he/she used SAVER first whilst code P2S2 indicates that participant P2 used SAVER following a previous experiment.

**Table 5.2 Distribution of participants**

<b>Participant (Identifier)</b>	<b>Experience (Years)</b>	<b>Participated in one or more National Exercises</b>	<b>Participated in one or more emergency events</b>
P1	3 – 4	YES	NO
P2	3 – 4	YES	NO
P3	5 – 6	YES	YES
P4	0 – 2	YES	NO
P5	3 – 4	YES	NO
P6	5 – 6	YES	YES
P7	3 – 4	YES	NO
P8	5 – 6	YES	NO
P9	7 – 8	YES	YES
P10	3 – 4	YES	NO
P11	7 – 8	YES	NO
P12	0 – 2	YES	NO
P13	5 – 6	YES	YES
P14	7 – 8	YES	YES
P15	0 – 2	YES	NO
P16	5 – 6	YES	YES

### 5.5.1.5 Instrument and scenario

A tsunami scenario was used during the experiments. The individuals were supposed to complete a situation report about the prevailing situation. Information about the earthquake parameters, wave attributes like heights, location etc. were provided to individuals in the form of four feeds. Each of the information feeds was followed by a question and answer session. SAVER provided information to the users according to the SA oriented design principles described above and also provided some analysis of the incoming information as described in the section “5.4. SAVER Features”, above. During the task, the session was frozen and a web based application opened a question in front of the participant. As soon as the question appeared on the screen, a timer also appeared with the question, encouraging the participant to answer as soon as possible. Once the participant has answered all the questions, he/she can continue with the task. Participants were asked directly about the situation, e.g., what is the location of the earthquake source? Similar questions were asked on every freeze. See Figure 5.8 below for an example question.



The screenshot shows a web-based application interface for a SAGAT query. At the top center, a large digital timer displays "00:00:00". Below the timer, the question is presented: "According to your understanding of wave speed what is predicted arrival time of wave at Auckland coasts ?". A subtext provides an example: "(e.g. 1400 or 2pm)". Below the question is a text input field with a yellow border. At the bottom center of the interface is a yellow "Submit" button.

Figure 5.8 Example SAGAT query

On the other hand, when participants were not using SAVER, they were provided with a soft copy of a document containing information in the format provided by the *United States Geological Survey* (USGS<sup>21</sup>) website used to publish earthquake information. In addition, information about the wave parameters and tsunami warnings etc. was

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<sup>21</sup> <http://www.usgs.gov/>

provided in the format of Pacific Tsunami Warning Centre (PTWC<sup>22</sup>) website that provides Deep Ocean Assessment and Reporting Tsunami (DART) data. See the example Figure 5.9 below for data provided to the non-SAVER user.

DART sensors in the area provide the following wave information.

MEASUREMENTS OR REPORTS OF TSUNAMI WAVE ACTIVITY ISSUED AT T5 2305Z 01 APR

GAUGE LOCATION	LAT	Lon	TIME	AMPL	PER
240NM Manzanillo, Mexico	15.0N	110.0W	0244Z	1.31M = 4.3FT	14MIN
360NM Acapulco, Mexico	12.0N	100.0W	0124Z	1.58M = 5.2FT	22MIN
710NM Panama City, Panama	05.0N	090.0W	0135Z	1.88M = 6.2FT	12MIN
400NM Southeast of Tonga	08.4S	125.0W	0040Z	1.09M = 3.6FT	40MIN
640NM Auckland, New Zealand	33.0S	173.0W	2308Z	1.40M = 4.6FT	62MIN

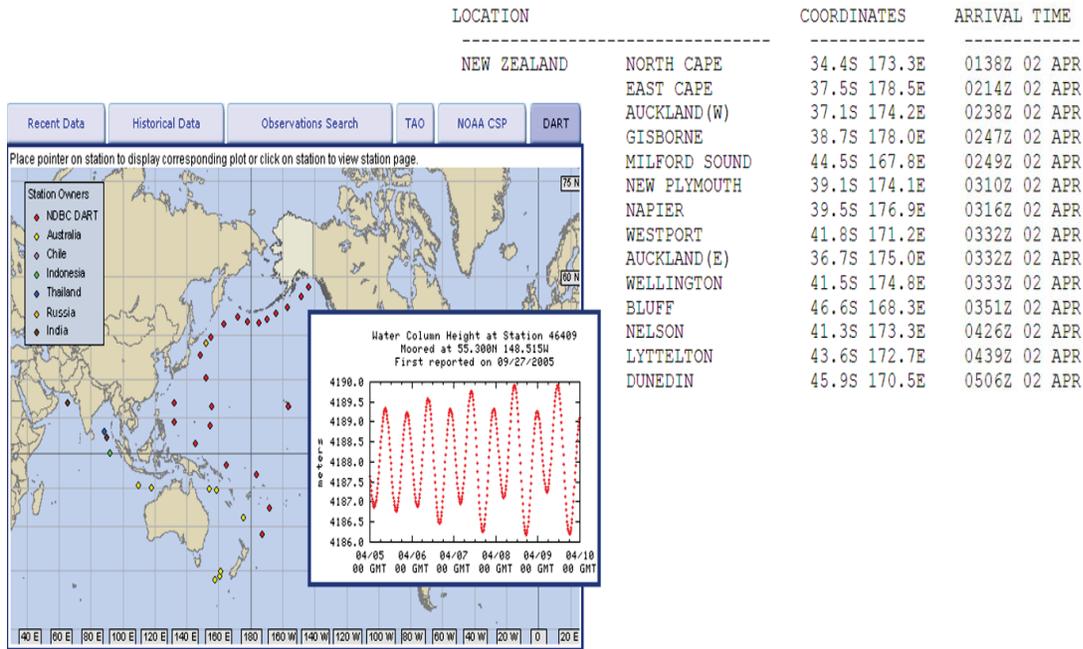
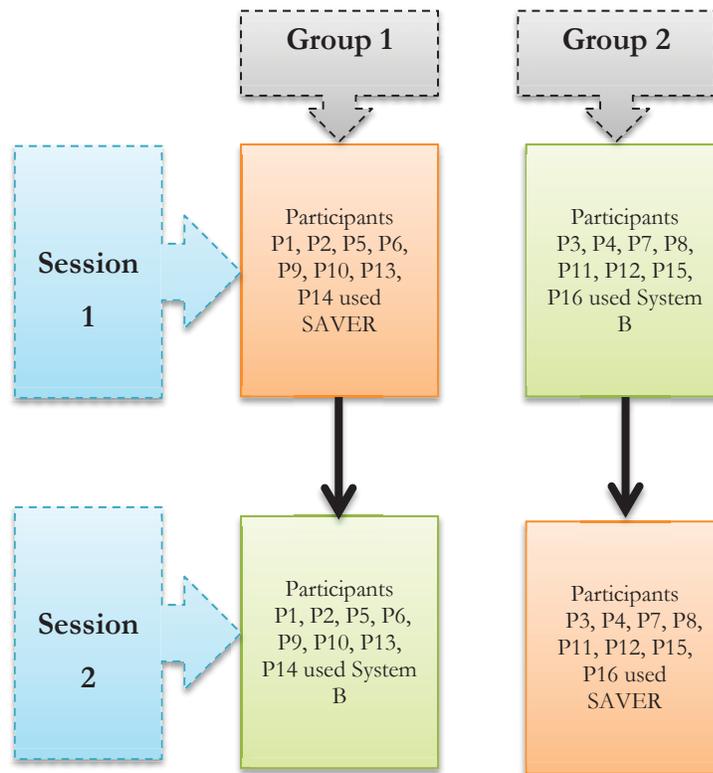


Figure 5.9 Data for non-SAVER user

To reduce learning bias, experiments were done in two parts on two different days (Session 1 and Session 2) more than a week apart. Out of the total sixteen participants, eight individuals were asked to perform the experiment with SAVER first and then without SAVER (Group 1), and the other eight individuals were asked to perform experiments without SAVER first and then with SAVER (Group 2) as shown in Figure 5.10 below.

<sup>22</sup> <http://ptwc.weather.gov/>



**Figure 5.10 Order of the experiments**

#### ***5.5.1.6 Response variables***

Two response variables were used in the experiment:

1. The percentage of correct responses to the SA queries targeting different levels of SA, i.e. perception (SA1), comprehension (SA2), and projection (SA3)
2. The time taken to answer each question

An SA query pool was developed to assess the possible effect of using SAVER on the participants' SA. Queries were designed to cover every level of SA. Level 1 SA queries were structured to determine if participants were able to identify and remember the important or critical elements of the emergency situation required to predict tsunami generation. Level 2 SA queries were designed to determine if participants have successfully analysed the situation elements as e.g. earthquake magnitude is high or low and wave heights are normal or high and successfully related them to their goal and task. Queries for Level 3 SA were designed to find if participants had successfully predicted the future states of the situation, e.g. possibility of situation generation, from Level 1

and 2 SA information. The level 1, 2, and 3, queries included nine, four, and three questions respectively.

Example responses to SA queries are shown in Table 5.3 below. Participant responses to the SA queries were graded based on the ground truth for the simulation using a five-point scale ranging from *Highly likely* to *Not likely at all*. To get an SA measure for every participant at each SA level, all the query results of the participant related to that SA level are aggregated and averaged.

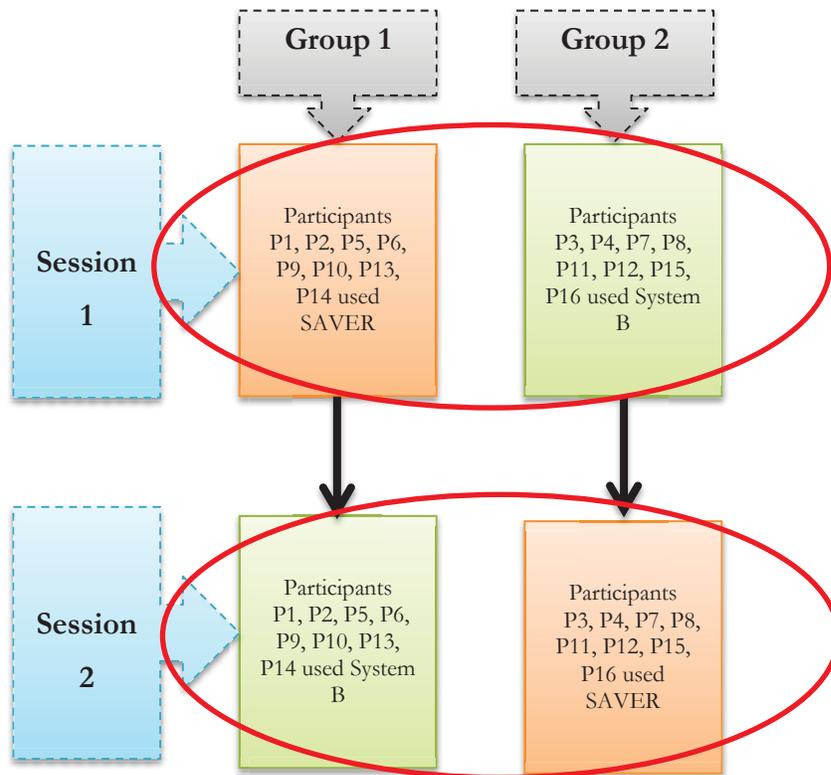
**Table 5.3 A sample of SA query pool and example responses**

SA Level	Question	Ground truth (Answers)
1	What was the magnitude of earthquake?	8.1
1	What was the depth of earthquake source?	28km
1	What was the location of the earthquake source (coordinates)?	15.0 W 115.0 N
2	According to your interpretation, earthquake magnitude is _____ to generate a tsunami.	High Enough
2	Was Earthquake source offshore or onshore?	Offshore
2	According to your understanding of source depth and location, what is the likelihood that it can cause a tsunami?	Likely
3	According to your understanding of situation, how likely is tsunami generation?	Likely

## 5.5.2 Experiment results

### 5.5.2.1 Validity of the experiment method

To ensure that participants in the second session were not influenced by learning from the first, the performance of the two groups in Session 1 are compared with their performance in session 2 as illustrated in Figure 5.11. The results of these two groups were cross checked using independent sample T-test using significance level  $p < 0.05$ . No significant difference between their performances was found ( $t = -0.56$ ,  $p\text{-value} = 0.577$ ) confirming that the performance of the participants ( $M = 86.6$ ,  $S.D = 8.90$ ) was not affected by the previous experiment session ( $M = 84.8$ ,  $S.D = 9.10$ ), where M stands for *Mean* and S.D stands for *Standard Deviation*.

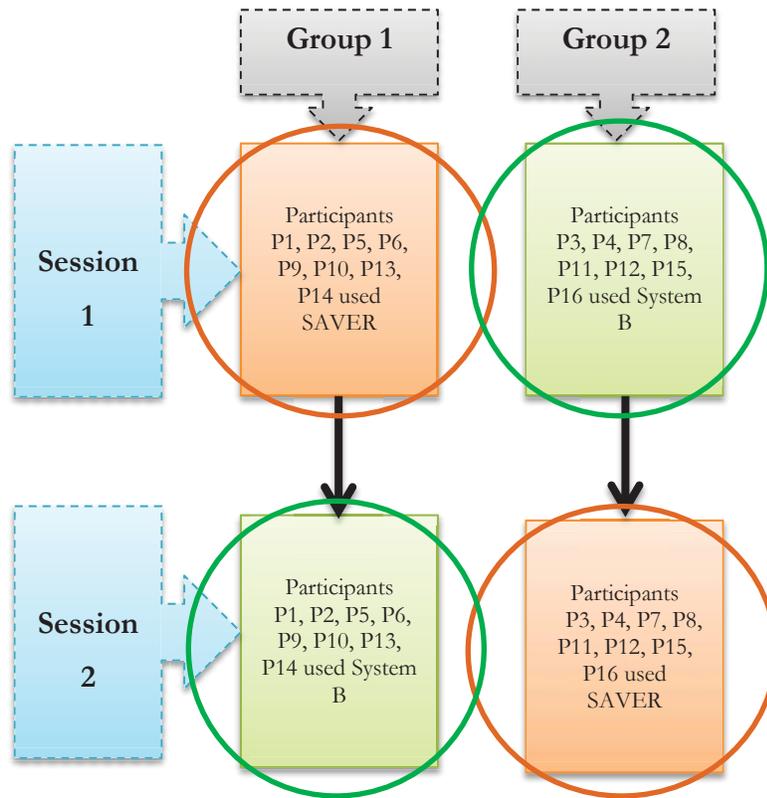


**Figure 5.11 Order of experiments red circles showing the two groups of participants**

However, the possibility still exists that the average percentage across Group 1 and Group 2 in Session 1 is the same as the average percentage across these groups in Session 2. Therefore, further tests were conducted to confirm that participants did not use the learning from the previous session as it is very critical for the valid evaluation of SAVER. The performance of SAVER users who performed the experiment first (Group 1, Session 1) is compared with the performance of those SAVER users who performed the experiment in the second session (Group 2, Session 2) as shown by the orange circles in Figure 5.12 below. The results of this comparison using independent sample T-test revealed there is no significant difference ( $t = -1.10$ ,  $p\text{-value} = 0.28$ ) between the performance of both the groups ( $M = 90.5$ ,  $S.D = 5.97$  for using SAVER in the first session; and  $M = 93.0$ ,  $S.D = 3.65$  for using SAVER in the second session).

Moreover, the performance of non-SAVER users who performed the experiment first is compared with the performance of those non-SAVER users who performed the experiment in the second session as shown by the green circles in Figure 5.12 below. The results of this comparison using independent sample T-test also proved that there is

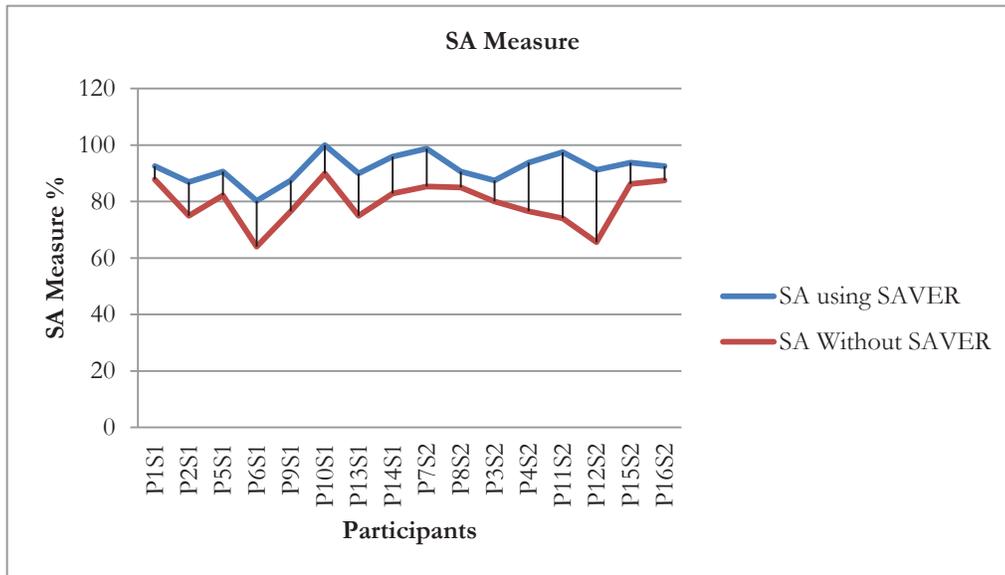
no significant difference ( $t = -0.21$ ,  $p\text{-value} = 0.83$ ) between the performance of both groups ( $M = 79.2$ ,  $S.D = 8.31$  for the non-SAVER users in the first session; and  $M = 80.0$ ,  $S.D = 7.58$  for the non-SAVER users in the second session).



**Figure 5.12 Comparing performance of the SAVER users (orange circles) and non-SAVER users (green circles) in the first session with the second session**

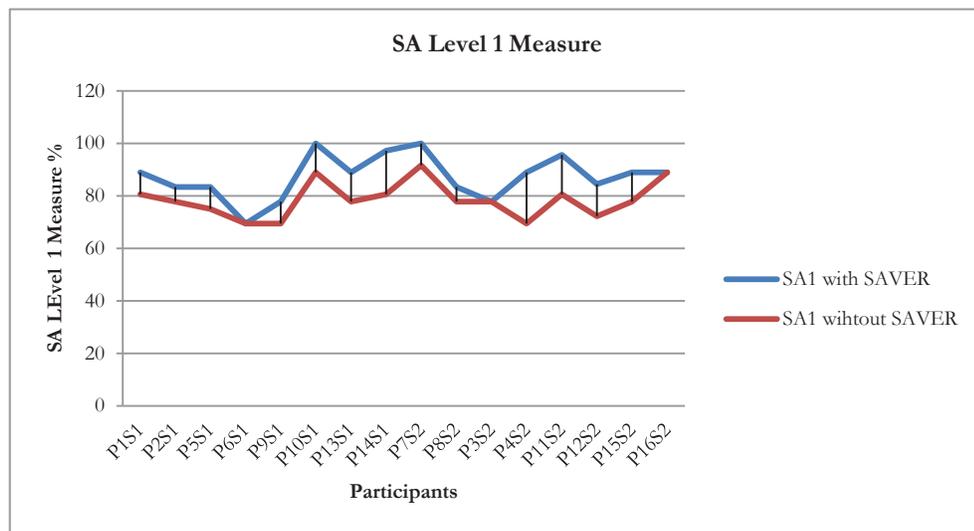
#### **5.5.2.2 SA measurement by score with and without SAVER**

The results of the individual SA measurements (see Figure 5.13 below) shows that the individuals who used SAVER performed very well compared with those who did not use it. Moreover, paired sample T-test was conducted and a significant difference ( $t = -2.84$ ,  $p\text{-value} = 0.008$ ) was found between the score without using SAVER ( $M=73.0$ ,  $S.D=10.5$ ) and the score of participants using SAVER ( $M=82.58$ ,  $S.D=8.40$ ).



**Figure 5.13 Comparison of Individual SA measures with and without SAVER**

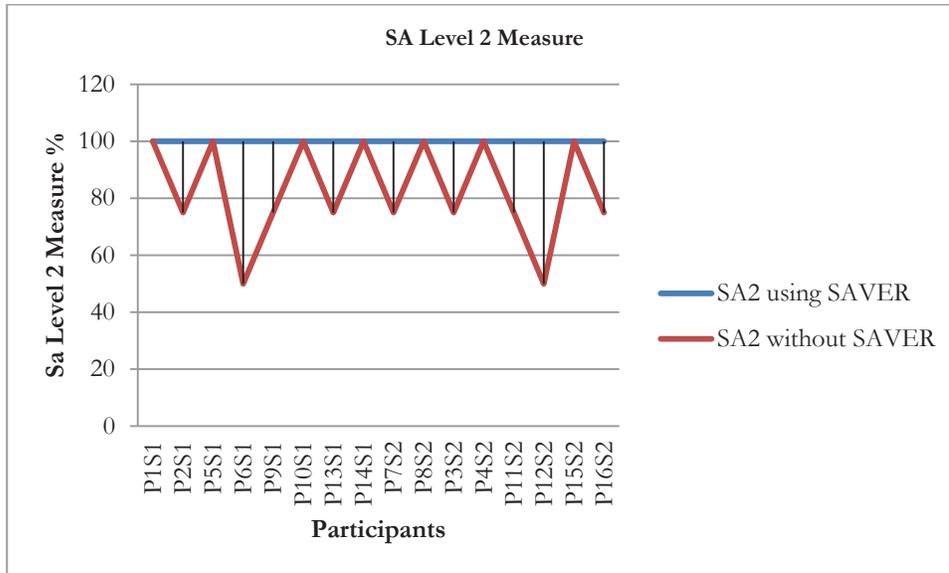
Results are further broken down into the three levels of SA. Therefore, answers for the questions targeted on each level of SA are isolated according to the SA level and the percentage averaged to provide the user’s SA on that SA level. Figure 5.14 below presents Level 1 SA for the individuals.



**Figure 5.14 Comparison of the SA Level 1 measures with and without SAVER**

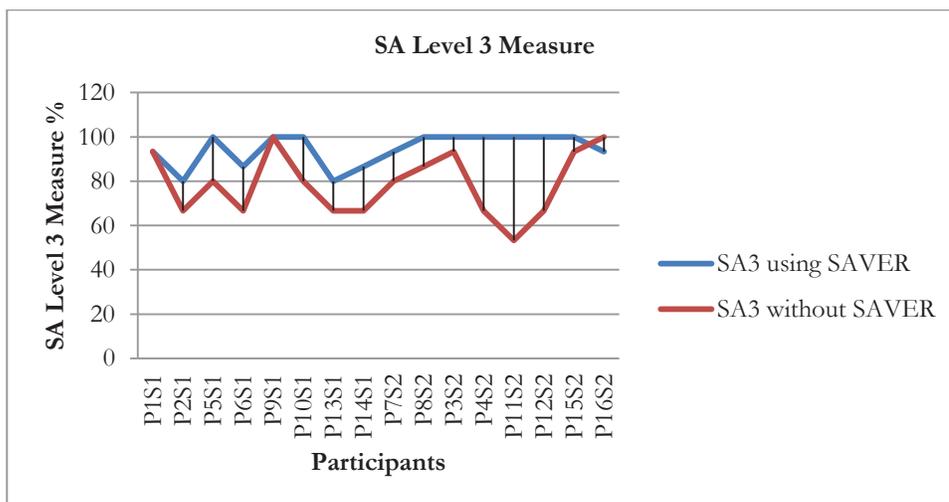
The result of measuring a shared Level 1 SA using and without using SAVER, shows that there is an improved performance by those who were using SAVER during the

experiment. Paired sample T-test shows that a significant difference ( $t = -3.26$ ,  $p\text{-value} = 0.003$ ) is found in the score of participants using SAVER ( $M=88.4$ ,  $S.D=8.94$ ) and the score for individuals not using SAVER ( $M=78.5$ ,  $S.D=6.84$ ). Figure 5.15 below presents Level 2 SA for the individuals.



**Figure 5.15 Comparison of the SA Level 2 measures with and without SAVER**

Figure 5.15 shows the results of measuring Level 2 SA with and without SAVER. The results show that use of SAVER improves SA Level 2. Paired sample T-test shows that a significant difference ( $t = -3.90$ ,  $p\text{-value} = 0.001$ ) is found in the score of participants not using SAVER ( $M=82.8$ ,  $S.D=17.6$ ) and the score for using SAVER ( $M=93.7$ ,  $S.D=7.39$ ). Figure 5.16 below presents Level 3 SA for the individuals.



**Figure 5.16 Comparison of SA Level 3 measures with and without SAVER**

Figure 5.16 shows the results of measuring SA Level 3 with and without SAVER. The result again shows that SAVER improves SA at Level 3. Paired sample T-test shows that a significant difference ( $t = -3.90$ ,  $p\text{-value} = 0.001$ ) is found in the score of participants not using SAVER ( $M=78.7$   $S.D=14.44$ ) and the score of participants using SAVER ( $M=93.7$   $S.D=7.39$ ).

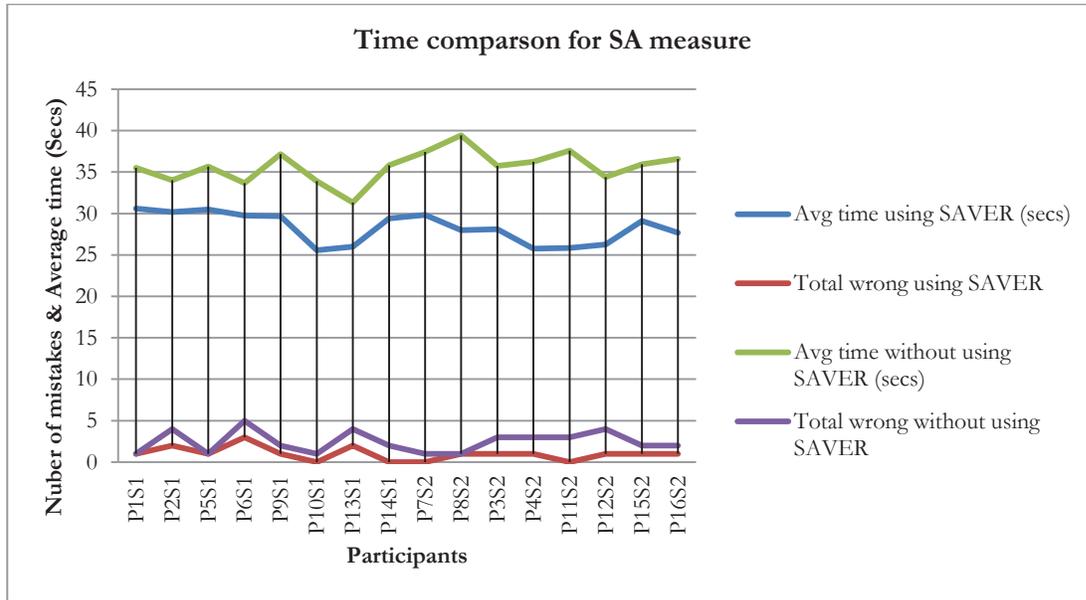
The results above show that the individual SA on all three levels was improved by using SAVER during the experiments. It appears that the SAVER's SA-oriented design improved SA by providing the individuals with information in a format that helped them to improve their attention and also remember the details by supporting their short term memory with relevant information processing. Similarly, by sharing the interpretation of a situation and the prediction about the evolving situation, updated the individual's SA. Moreover, the SA of SAVER users was also better than the non-SAVER users because the demand on an individual's cognitive resources was lower when SAVER was doing most of the processing for them, and when they were considering its recommendations and suggestions for answering the questions.

This last observation was also supported by using other questions in the survey in which users were asked to rank the sources that they used every time they answered complex questions. Most of the users who were not using SAVER, ranked previous experience as their first priority and communication as the second, whereas most of the individuals who used SAVER preferred SAVER's suggestions to their own experience. However, this result could be attributed to the fact that the experiment was a simulation and not a real event.

### ***5.5.2.3 Analysis of SA measure by time***

Since time is an important factor in emergency decision-making, it is also scarce in such situations. By reducing the time required to develop the needed level of SA for decision making or carrying out a task, the overall emergency management operations can highly improve. This can enable effective and efficient decision making and task completion in a short time. The time taken by participants to answer every question was recorded to see whether there is some difference between the response time of SAVER and non-SAVER users in understanding the questions about a situation. A graph in Figure 5.17 below shows the comparison of average time taken by every participant to answer each

question, with and without using SAVER. Moreover, it also shows the count of wrong answers.



**Figure 5.17 Comparison of average time taken by a user to answer the queries and count of wrong answers using and without using SAVER**

In Figure 5.17 we can see that the time to answer each question has considerably reduced when users were using SAVER, almost all the users were able to recall the situation elements, their comprehension and projection more quickly using SAVER than without using SAVER. Therefore, time to answer queries was relatively less since SAVER’s suggestions were helping them to understand the situation quickly. The last point was also confirmed by the answer to one of the HCI evaluation questions, in which users were asked whether SAVER helped them in quickly recalling the situation parameters and almost all of the users agreed. A paired sample t-test shows that a significant difference ( $t = -12.06$ ,  $p\text{-value} = 0.000$ ) is found in the average time taken by the users to answer queries, using SAVER ( $M=28.3$ ,  $S.D=1.85$ ) and without using SAVER ( $M=35.6$ ,  $S.D=1.90$ ).

The graph in Figure 5.17 also shows the count of numbers of mistakes made by each user. It can be seen the users made a relatively small number of mistakes when they were using SAVER than while not using SAVER.

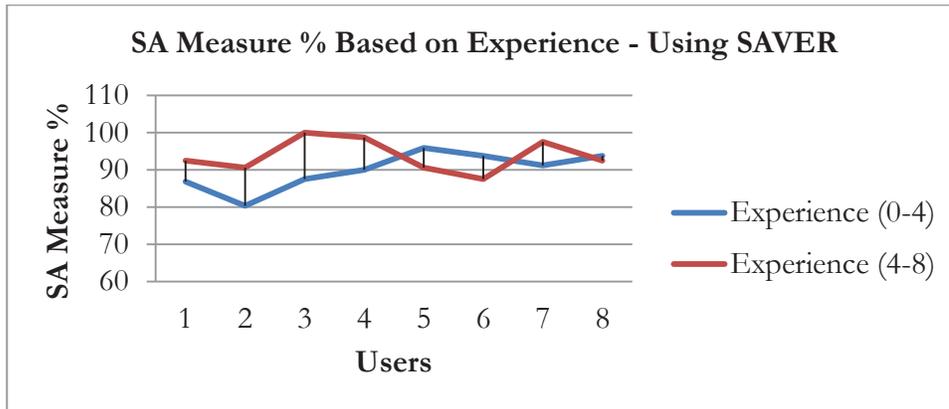
#### 5.5.2.4 Analysis of SA measure by user experience

Experience is an important factor in emergency decision making since SA required by a decision maker can be highly influenced by his/her experience level (Endsley, 1995a; Klein, 1999). However, as discussed in the “Problem identification” section of this chapter, experienced emergency managers are scarce in emergency situations and they can also make mistakes in highly dynamic and complex situations. Therefore, SAVER is designed to directly update a user’s SA on all three levels and it is intended to equally support experienced and novice emergency managers. Data about the experience of participants (emergency managers) was collected before the experiments using the ranges of 0 to 2 years, 3 to 4 years, 5 to 6 years, 7 to 8 years, or more than 8 years of experience. Responses show that all the participants have experience between 0 to 8 years so that experienced and novice emergency managers were divided into two main groups i.e. 0 to 4 years and 5 to 8 years. This grouping is shown in Table 5.4 below:

**Table 5.4 Grouping of participants based on years of experience**

Participant (Identifier)	Experience (Years)	Participated in one or more National Exercises	Participated in one or more emergency events	Experience (Years)
P2	3 – 4	YES	NO	0 - 4
P4	0 – 2	YES	NO	
P15	0 – 2	YES	NO	
P1	3 – 4	YES	NO	
P10	3 – 4	YES	NO	
P12	0 – 2	YES	NO	
P7	3 – 4	YES	NO	
P5	3 – 4	YES	NO	
P13	5 – 6	YES	YES	5 – 8
P8	5 – 6	YES	NO	
P11	5 – 8	YES	NO	
P9	7 – 8	YES	YES	
P16	5 – 6	YES	YES	
P6	7 – 6	YES	YES	
P3	5 – 6	YES	YES	
P14	7 – 8	YES	YES	

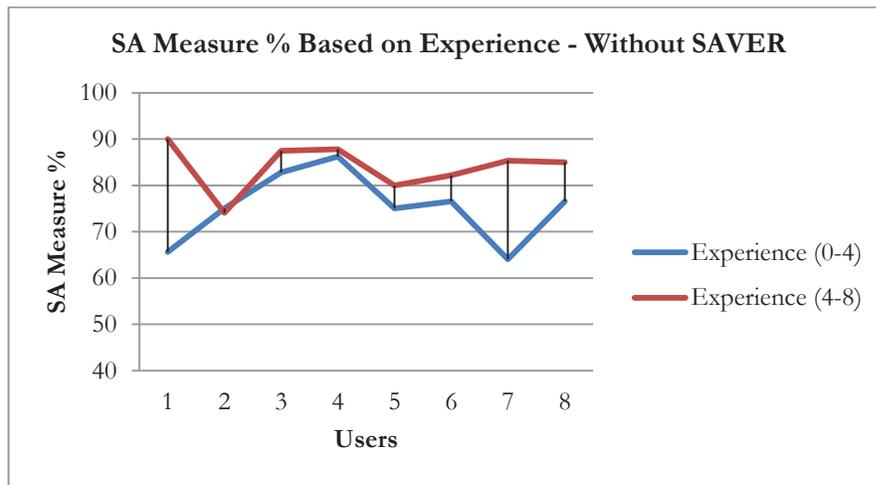
Moreover, all the emergency managers had experience of actively participating in one or more national level exercises. Almost 80% of the emergency managers who have 4 to 8 years of experience have also participated in one or more real emergency events. Whereas, none of the emergency managers with experience of 0 to 4 years had participated in a real emergency event. The graph in Figure 5.18 below shows the performance of both groups using SAVER in overall SA measure.



**Figure 5.18 Comparison of SA performance based on experience using SAVER**

Figure 5.18 shows that the performance of emergency managers with more experience (5 to 8 years) is slightly better than those with lesser experience (0 to 4 years). However, the comparison using independent sample T-test shows that there is no significant difference ( $t = -1.61$ ,  $p\text{-value} = 0.13$ ) in the performance of both groups of emergency managers. Hence, SAVER has supported the novice emergency managers ( $M=89.9$ ,  $S.D=4.99$ ) to a degree that their performance is brought near to the performance of experienced emergency managers ( $M=93.7$ ,  $S.D=4.46$ ).

To confirm it further, the performance of the emergency managers without using SAVER is tested based on the experience level. Figure 5.19 shows the performance of emergency managers without using SAVER based on experience.



**Figure. 5.19 Comparison of SA performance based on experience without SAVER**

The performance of emergency managers with more experience (5 to 8 years) is significantly better than those who have lesser experience (0 to 4 years). Moreover, independent sample T-test shows that there is a significant difference ( $t = -2.71$ ,  $p\text{-value} = 0.01$ ) in the performance of both groups of the emergency managers ( $M=75.2$ ,  $S.D=7.55$  for novice and  $M=83.9$ ,  $S.D=5.12$  for experienced emergency managers). This confirms the argument that the SA of decision makers is affected by their experience levels (Endsley, 1995a; Klein, 1999). Therefore, the effect of using SAVER becomes clear in improving the performance of both the novice and experienced emergency managers.

### **5.5.3 Human Computer Interface (HCI) evaluation of SAVER**

#### ***5.5.3.1 HCI Experiment design***

Human Computer Interface (HCI) of a system plays an important role in improving the SA of the users (Endsley & Jones, 2001). Evaluation of HCI is therefore important to make sure the system is usable and useful. The emergency managers evaluated the HCI of SAVER by filling in a questionnaire after the experiments, based on usability and functionality (Bevan, 2001; ISO 9126-1, 1998).

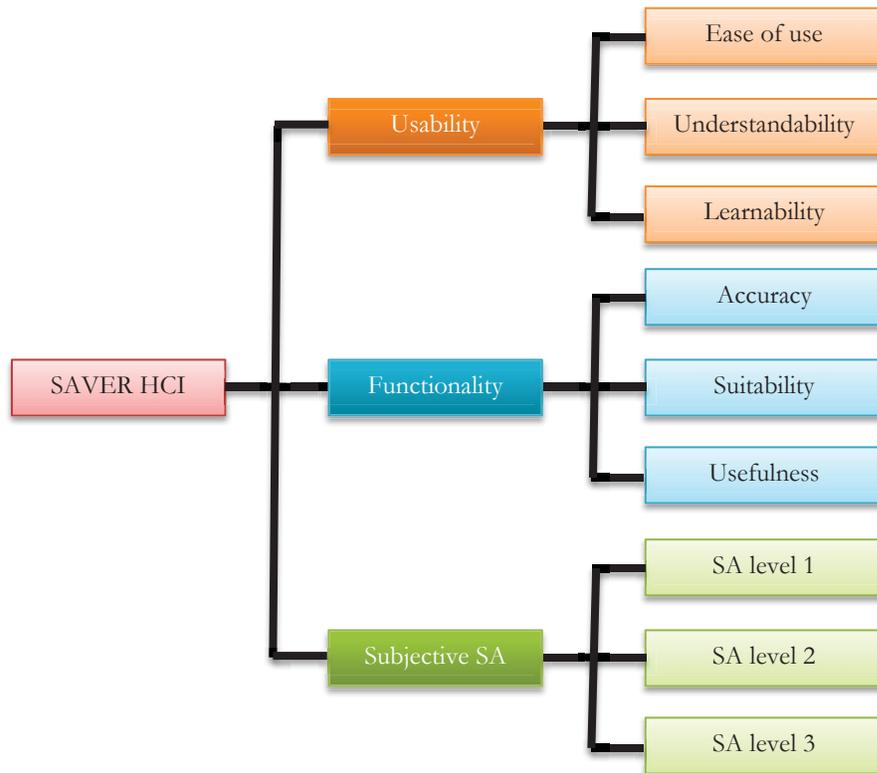
The following measurable attributes of usability as described in (ISO 9126-1, 1998; Folmer & Bosch, 2004) were used:

- Ease of use is the capability of software that enables the user to believe that using the software requires less effort to use (Bevan, 2001; Davis, 1989).
- Understandability is the capability of the software product that enables the user to understand the role of software in the given conditions.
- Learnability is the capability of the software product that enables the user to learn its use to perform the desired task
- Operability is the capability of the software product that enables the user to operate and control it.

The following measurable attributes of functionality as described in (ISO 9126-1, 1998; Folmer & Bosch, 2004) were used:

- Accuracy is the capability of the software that provides the correct and desired information as expected by the user for the given conditions.
- Suitability is the capability of the software that enables the user to recognise whether the use of software is suitable for the given task or not. Moreover, it describes the tasks and conditions of the software use.
- Usefulness is the capability of the software that enables the user to perceive whether the use of the software improved his/her performance (Davis, 1989) i.e. user's effectiveness and efficiency to perform his/her task.

Though usefulness and overall functionality of SAVER have already been evaluated in the previous section and Chapter 4, this section evaluates the perceived usefulness, accuracy, and suitability of SAVER by asking users to rate the attributes on a scale. Moreover, the HCI of SAVER is also evaluated in terms of subjective queries about the SA of the user. These queries were targeted at all three levels of SA and users were asked about the degree of their SA at different levels of SA. Figure 5.20 below summarises the measurable attributes of HCI factors used in the evaluation.



**Figure. 5.20 HCI factors and their measurable attributes**

A questionnaire comprising 18 questions attempted to address all the measurable attributes described above. The order of the questions was deliberately mixed to avoid random ratings by the participants. However, in the analysis, the questions are described according to the HCI factors (usability, functionality, SA subjective measure). Each question was rated on a seven-point Likert scale where 1 was “strongly disagree” and 7 was strongly agree. Figure 5.21 below shows the example queries about the HCI of SAVER.

<b>Suggestions provided were easy to understand *</b>							
	1	2	3	4	5	6	7
Strongly disagree	<input type="radio"/>	Strongly agree					
<b>Lot of training was needed to use SAVER *</b>							
	1	2	3	4	5	6	7
Strongly disagree	<input type="radio"/>	Strongly agree					
<b>SAVER is easy to use *</b>							
	1	2	3	4	5	6	7
Strongly disagree	<input type="radio"/>	Strongly agree					

**Figure. 5.21 The example queries about the HCI of SAVER**

### 5.5.3.2 Usability questionnaire responses

The overall usability of SAVER is measured by asking the questions about each attribute of usability as described above. Table 5.5 below shows all the questions relating to the usability of SAVER. Question U1 was intended to measure the “learnability” attribute of usability, whereas questions U2 and U3 were anticipated to measure the “ease of use” attribute of usability metric. In order to check the degree of the understandability attribute of usability, questions U4, U5, and U6 were used.

The responses to question U1 show that the participants found it very easy to learn the use of SAVER. A one sample T-test against the neutral rating value 4.00 confirmed these interpretations ( $t = -5.96$ ,  $p\text{-value} < 0.001$ ). In addition, responses to the questions U2 and U3 reveal that SAVER was very easy to use and navigation through the system was very straight forward ( $t = -5.83$ ,  $p\text{-value} < 0.001$  for question U2;  $t = 4.25$ ,  $p\text{-value} = 0.001$  for question U3). Moreover, responses to the questions U4, U5, and U6 indicate that the suggestions provided by SAVER about the perception, comprehension and projection of the situation are very easy to understand ( $t = 10.95$ ,  $p\text{-value} < 0.001$  for question U4;  $t = 12.65$ ,  $p\text{-value} < 0.001$  for question U5 and  $t = 11.22$ ,  $p\text{-value} < 0.001$  for question U6).

**Table 5.5 Responses to questions related to the usability of SAVER**

Question Number	HCI Attribute	Question / Statement	Response Mean
U1	Learnability	Lot of training was needed to use SAVER	2.6 (disagree)
U2	Ease of use	SAVER was easy to use	5.2 (agree)
U3	Ease of use	Navigation was easy to follow	5.1 (agree)
U4	Understandability	Suggestions provided were easy to understand	6.0 (agree)
U5	Understandability	Comprehension of the situation provided was easy to understand	6.0 (agree)
U6	Understandability	Projection of the situation provided was easy to understand	5.43 (agree)

All these results show that the participants have positively rated all of the attributes of usability. This result confirms that SAVER is easy to use and learn and its suggestions are all understandable.

### ***5.5.3.3 Functionality questionnaire responses***

In order to know how the emergency managers perceived the functionality of SAVER, a questionnaire addressed all the fundamental attributes of the functionality like accuracy, suitability and usefulness. The questions F1, F2, and F3 were intended to measure the suitability aspect, questions F4 and F5 were anticipated to measure accuracy aspects, and questions F6, F7, F8, F9, and F10 presented aspects of usefulness. All these questions are described in Table 5.6 below.

**Table 5.6 Responses to questions related to the functionality of SAVER**

<b>Question Number</b>	<b>HCI Attribute</b>	<b>Question / Statement</b>	<b>Response Mean</b>
F1	Suitability	SAVER guided me to improve my Situation awareness	5.6 (agree)
F2	Suitability	Given suggestions were relevant (according to the task)	5.6 (agree)
F3	Suitability	Given suggestions were timely (according to situation)	5.4 (agree)
F4	Accuracy	SAVER interface flow was as expected	5.4 (agree)
F5	Accuracy	SAVER suggestions were as expected	5.5 (agree)
F6	Usefulness	SAVER helped me in quickly recalling situation elements	4.7 (agree)
F7	Usefulness	SAVER helped me quickly comprehending the situation	5.0 (agree)
F8	Usefulness	SAVER helped me quickly projecting (predicting) about situation	4.7 (agree)
F9	Usefulness	SAVER helped me achieving my tasks effectively	5.0 (agree)
F10	Usefulness	SAVER helped me achieving my tasks efficiently	5.0 (agree)

Generally, the responses to all the questions about functionality of SAVER were positive. One sample T-test against the neutral rating value 4.00 for each question is used to establish the interpretation of the responses. The responses to question F1 show that the participants perceived that SAVER has significantly improved their SA ( $t = 7.00$ ,  $p\text{-value} < 0.001$ ). In addition, responses to questions F2 and F3 reveal that SAVER's suggestions were very relevant according to the task ( $t = 6.48$ ,  $p\text{-value} < 0.001$  for question F2) and situation ( $t = 7.06$ ,  $p\text{-value} < 0.001$  for question F3) indicating the overall suitability of SAVER for the given task in the provided situation.

Moreover, responses to questions F4 and F5 illustrate the flow of operation and the outputs of SAVER were accurate ( $t = 11.22$ ,  $p\text{-value} < 0.001$  for question F4 and  $t = 11.61$ ,  $p\text{-value} < 0.001$  for question F5). In addition, the responses to the questions F6, F7, F8, F9 and F10 suggest that SAVER has considerably helped them in quickly recalling the situation elements ( $t = 3.5$ ,  $p\text{-value} = 0.003$  for question F6), comprehending the situation ( $t = 3.78$ ,  $p\text{-value} = 0.002$  for question F7), and predicting about the situation ( $t = 2.81$ ,  $p\text{-value} = 0.01$  for question F8). Furthermore, the responses to questions F9 and F10 demonstrate that SAVER has highly supported the participants in performing their tasks effectively ( $t = 5.5$ ,  $p\text{-value} < 0.001$  for question F9) and efficiently ( $t = 4.14$ ,  $p\text{-value} = 0.001$  for question F10). All these results confirm that SAVER is functioning properly in the aspects of accuracy, suitability, and usefulness and according to the expectations of its users (emergency managers).

#### ***5.5.3.4 SA subjective measure questionnaire responses***

The questions listed in Table 5.7 were intended to ascertain what participants perceived about the degree of their own SA on each level of SA after using SAVER. A subjective measure of SA is usually calculated by self-rating techniques like Situation Awareness Rating Technique (SART) (Taylor, 1990). SART is performed post trials and involves the participant rating various aspects (familiarity of situation, focusing of attention, quantity of information etc.) of SA on a seven point rating scale (1 low and 7 high) in order to gain a subjective measure of SA (Salmon et al., 2009). Question "SA1" was anticipated to measure the perceived degree of Level 1 SA, question "SA2" was intended to measure the perceived degree of Level 2 SA and question "SA3" was presented to measure the perceived degree of Level 3 SA of the participants.

The overall responses to the questions show that the degree of perceived SA of each participant was very high after using SAVER. The responses to question SA1 show the participants' supposition that they had a high degree of awareness of the situation elements ( $t = 5.83$ ,  $p\text{-value} < 0.001$  for question SA1). The replies to question SA2 reveal the participants' assumption that they have comprehended the situation elements very well ( $t = 10.43$ ,  $p\text{-value} < 0.001$  for question SA2). Furthermore, answers to question SA3 indicate the participants' belief that they predicted the situation very well during the experiment using SAVER ( $t = 6.26$ ,  $p\text{-value} < 0.001$  for question SA3). All these results illustrate that the degree of perceived SA at every level was very high.

**Table 5.7 Responses to related subjective measure of SA using SAVER**

Question Number	Subjective SA measure	Question / Statement	Response Mean
SA1	SA level 1	I correctly identified the situation elements	5.2 (agree)
SA2	SA level 2	I correctly comprehended the situation elements	5.9 (agree)
SA3	SA level 3	I correctly predicted the future states of situation	5.1 (agree)

## 5.6 Summary and Conclusions

In emergency management, to achieve a goal, certain tasks are performed, each of which requires a certain level of SA for successful completion. An individual's SA in emergency situations is affected by many cognitive factors like short and long term memory, stress level, mental models etc. These factors are highly dependent on the individual's level of experience and affect SA at different levels. Getting the wrong perception of the situation elements can lead to wrong decisions. Moreover, as the mental models are linked with experience and usually the highly experienced emergency managers are scarce in emergencies; there is a high risk of misunderstanding the situation by novice emergency managers. Use of a computer based system can address these issues but such solutions come with problems such as how to design a system providing support to an individual's SA, whether a computer based SA can improve an individual's SA and how to design and evaluate the interface of such systems.

The capability of an information system to support decision makers depends on how well the system supports their goals. The contextual parameters, i.e. his/her role, responsibilities, objectives and tasks are also very important to provide the right information to the right people at the right time to achieve their goals.

Instead of a computer based system which provides information on request, a computer system is needed which can work as a team member and share information proactively with the understanding of the information and logical reasoning. Hence, automatic processing of contextual information is needed. A contextual information module and interface is designed and developed for SAVER (prototype developed in Chapter 4) to be used and evaluated by the emergency managers. SAVER uses ontological contextual modelling and reasoning. Ontologies provide the detailed semantics needed for automatic contextual information processing and reasoning. To design user interfaces for improved SA, SA oriented system design, which is a User Centred Design (UCD) approach, is used.

Since SAVER is intended to improve an emergency manager's SA, it is necessary to evaluate its effect by experiments. Measuring SA techniques are classified into direct or objective measurement of SA and indirect or subjective measurement of SA. The SA measurement technique used for direct measurement of SA is Situation Awareness Global Assessment Technique (SAGAT). SAGAT is used to measure SA on all three levels. This type of measurement directly taps into the operator's perception rather than inferring them from behaviours. Hence, SAGAT is the most widely used and accepted SA measurement technique

The results of evaluation show that the individual's SA on all three levels was improved by using SAVER during the experiments. It seems that SAVER's SA-oriented design improved SA by providing individuals with the information they needed to understand the situation. Moreover, by processing the information on their behalf also supported their cognitive resources like short term memory. Similarly, sharing the interpretation of the situation and prediction about the evolving situation, updated the individual's SA. Though this can be confirmed by further experiments for various roles.

Time is a very critical factor in emergency decision making. Reducing the time required to develop the needed level of SA for decision making or carrying out a task can highly improve overall emergency management operations. Analysis of the time taken by the

individuals to answer question about SA shows that time to answer queries was significantly less when the participants were using SAVER than when they were not. This can be because of SAVER's suggestions, which helped them to understand the situation quickly.

To dig deep into the effect of SAVER on an individual's SA, data analysis is also done on the basis of the user's experience, since the experience is an important factor in acquiring and maintaining SA. Participants are divided into two groups, i.e. novice and experienced emergency managers having experience of 0 to 4 years and 5 to 8 years respectively. Results show that the performance of the emergency managers with more experience (5 to 8 years) is slightly better than those with less experience (0 to 4 years). However, the difference in the performance of the two groups is not significant. Hence, the performance of the novice emergency managers is significantly improved to the level of experienced emergency managers. In addition, the performance of the experienced emergency managers using SAVER was considerably better than the non-SAVER users. However, when SA performance of the non-SAVER users is analysed it is noted that there is a considerable difference between the novice and experienced emergency managers. This was also confirmed by the independent sample T-test since the SA of decision makers is highly affected by their experience levels. Therefore, the improvement in the SA of novice and experienced emergency managers using SAVER is evident.

The user interface of SAVER is evaluated in terms of its usability and functionality. The measurable attributes of the usability used in this evaluation are; ease of use, understandability, learnability, and operability. Whereas the measurable attributes of functionality used in the evaluation of SAVER are accuracy, suitability, and usefulness. Results of the user interface evaluation show that the participants have positively rated all the attributes of usability confirming that SAVER is easy to use and easy to learn and its suggestions are all understandable. Furthermore, results from functionality evaluation also approve that SAVER is functioning properly in the aspects of accuracy, suitability, and usefulness.

SA is also measured by the indirect or subjective method namely Situation Awareness Rating Technique (SART). Responses to the SA queries show that all the SAVER users

perceived a high degree of SA on all three levels i.e. perception, comprehension, and projection.

Hence, all the research objectives set for this chapter are achieved by answering all the questions mentioned in the “problem identification” section of this chapter. SAVER’s contextual suggestions about the situation and information needed to develop and maintain SA have been proved useful by the detailed evaluation of SAVER. Moreover, the user interface of SAVER has also been evaluated positively. This proved that the design was successful in improving SA using a computer based system. Such a system with detail context information of all the involved roles and their responsibilities can considerably improve the decision making capabilities of emergency managers and can highly support them in performing their tasks effectively and efficiently.

# Chapter 6

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## IMPROVING SHARED AND TEAM SITUATION AWARENESS USING SAVER

### 6.1 Introduction

Multiple teams, e.g. Police, Healthcare, Emergency Managers usually manage large scale emergencies such as a tsunami or volcanic risk in highly populated cities etc. Consensus on important decisions and large collaborative tasks require effective co-ordination and co-operation in situations that are complex, dynamic, unfolding rapidly and invariably stressful. Close co-ordination within and between teams is essential since the failure of a single link can risk the whole operation. Computerised decision support systems can facilitate and improve co-ordination and decision making by presenting, structuring, processing, and interpreting huge amounts of information in a short span of time.

However, the power of such systems is enhanced even further if they are designed to improve the situation awareness (SA) of individual managers, their shared situation awareness (SSA) and team situation awareness (TSA). The goal is to ensure that team members have a comprehensive understanding of the situation not just for their individual roles but also of the roles of their colleagues

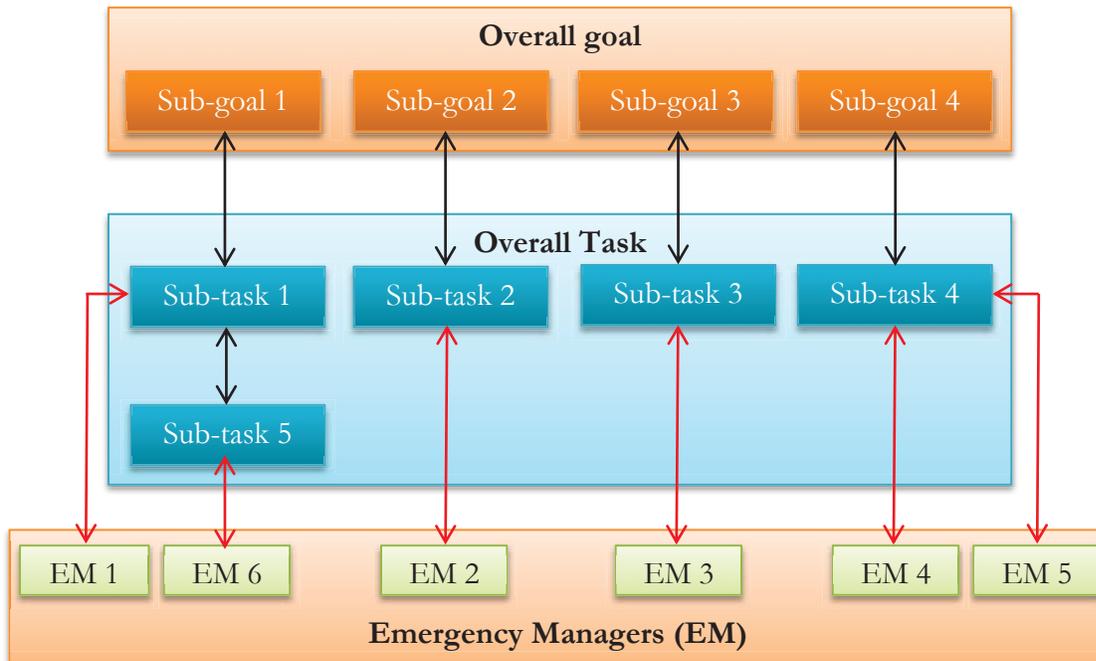
This chapter describes the design, development, and evaluation of the SAVER<sup>23</sup> extension to support SSA and TSA. The first section discusses the requirements of SSA and TSA and suggests a method to acquire them. The next section then explains the design and development of the solution prototype in the form of an extension to SAVER. The subsequent section evaluates SAVER to see if it supports the SSA and TSA of emergency managers. Conclusions are described in the last section.

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<sup>23</sup> Prototype system developed in Chapter 4 and Chapter 5

## 6.2 Problem Identification

Emergency managers working in teams may have one overall goal or objective but they can have different sub-goals defined by associated responsibilities and tasks that feed into the main goal. Figure 6.1 shows an example in which five emergency managers (EM 1 to 5) perform sub-tasks 1-4 that contribute to sub-goals 1-4. In the figure, manager EM6 performs sub-task 5, which feeds into sub-task 1 shared with EM1.



**Figure 6.1 Overall goal and task division for a team of emergency managers**

For the tasks which need multiple input from team members, e.g. sub-task 4,, team members should know which of their colleagues are doing what, and what they need and when, so they can provide the right information at the right time to the right person. However, as dozens of organizations can be involved in emergency operations it is not practical for an individual to remember all persons, teams, organizations and their related tasks along with relevant details. Requesting this information from other team members can involve considerable delays (MCDEM, 2008b; MCDEM, 2011).

Such collaborative tasks require emergency managers to share a common understanding of a situation so they can co-ordinate their decision making and actions. Different assessments of the situation can lead to unco-ordinated or even counter-predictive behaviour. The degree to which team members possess the same understanding of a

situation is defined as shared situation awareness (SSA) as it refers to the overlap between members' individual SA.

However, this overlap in itself may not be sufficient to achieve the required response to an emergency. Each team member's sub-goals demand the SA needed to discharge their role (responsibilities) in relation to other's activities. The degree to which every team member possesses this SA is known as team situation awareness (TSA). The TSA thus depends upon high levels of both individual SA and shared SA amongst members (Endsley & Jones, 1997, 2001). With low SA, individual members have a poor understanding of the situation, and with low SSA they tend to focus only on their own roles ignoring their team contribution and the actions of their colleagues. This not only results in the repetition of various activities but it can also delay or curtail tasks leading potentially to the failure of the whole mission due to the inability of team members to integrate their individual and shared awareness.

From the above, TSA can be viewed as an aggregate of every member's SA. Another form of TSA, which is very important for collaborative tasks, is the belief about the other team members' SA. For example, consider a team of two members. A and B, working together on a task. If member A believes that member B has misunderstood the situation, then the mistake can lead to failure of the task. If A's belief is correct about B's SA then A can update B's SA by providing him/her with the required information or by convincing him/ her about the situation.

When an event is catastrophic and mass evacuation is required, teams must decide if and when to evacuate and which areas to vacate etc. The team consensus about the prevailing situation and its implications needed for such decisions may be difficult to achieve due to the members' diverse roles and their cultural, background, and experience differences that make them understand and assess the situation differently. This problem becomes more complex as the number and type of roles involved in the team increases.

Considering all the problems discussed above, a need rises for a computer based system that considers the varied requirements of team members and provides them with an easily understandable analysis of the situation; that is a system that can support the shared SA and team SA of managers in emergency situations. However, the design and

development of such computer based systems need answers to some very fundamental questions. These questions are summarised below:

- a. How are SSA and TSA developed for team decision making and collaborative tasks?
- b. How to support SSA and TSA using a computer based system?
- c. Can a computer based system improve the SSA and TSA of emergency managers?

### **6.3 Suggested Solution to the Problem**

SSA and TSA can be improved by a computer based system that provides information to support the development and maintenance of the “degree of awareness”. The first step in designing such a computer system is therefore to identify the information requirements of SSA and TSA.

According to Endsley and Jones (2001), awareness of the team member’s requirements is viewed as SSA. Therefore, by reminding the team members about the other members’ requirements will improve the SSA of the whole team. Since SAVER can store the detailed information requirements of all team members, its design can be extended to support SSA by reminding the members about the requirements of their colleagues in a timely manner. This can be done by reasoning over the common goals, tasks and information requirements to reveal and install the necessary information flows. In this way, the workload of emergency managers will significantly reduce since they will not be required to remember the details of other members, organizations or roles that are dependent on them.

To support the common understanding of the situation, which is called TSA by Salas et al. (1995), SAVER can provide explicit situation assessment along with the reasoning. The reasoning in the form of logical arguments can clarify any doubts in the minds of emergency managers and they can be convinced about the prevailing situation. Moreover, providing them with the correct explanation of the situation generates a common and shared understanding among the team. Sharing of the member’s SA will improve the other team members’ confidence (if there is a match) or otherwise it will give them a chance to critically analyse the situation. A second look at the situation will enable team members to correct their own or another team member’s SA. Sharing of the team member’s SA will also improve the belief about the fellow team member’s SA, which is regarded as TSA by Shu and Furuta (2005).

Therefore, SSA and TSA can be supported and improved by a slight extension to the architecture of SAVER. The existing architecture can provide personalised information to the emergency managers if it has knowledge of the prevailing situation and its users' context (Chapter 5). The extension of semantic modelling of the situation and the user context can then promote automatic and proactive sharing of the information requirements between users who have given their consent for distribution. Automatic sharing of information without a team member's intervention reduces workload and task duration and improves the effectiveness and efficiency whilst proactive reminders can encourage members to supply information that SAVER cannot provide automatically. The information required to develop and maintain SSA can also be re-used from the information requirements gathered earlier (Chapter 4).

## **6.4 Design and Development**

This section focuses on the design and development of the extension for SAVER to support SSA and TSA. Since, an individual's SA can be supported by fulfilling his/her dynamic information needs in a particular domain (Endsley et al., 2003), the same can be done for SSA and TSA. The following section discovers the information needed to develop the SSA and TSA during the mass evacuation operation following a tsunami.

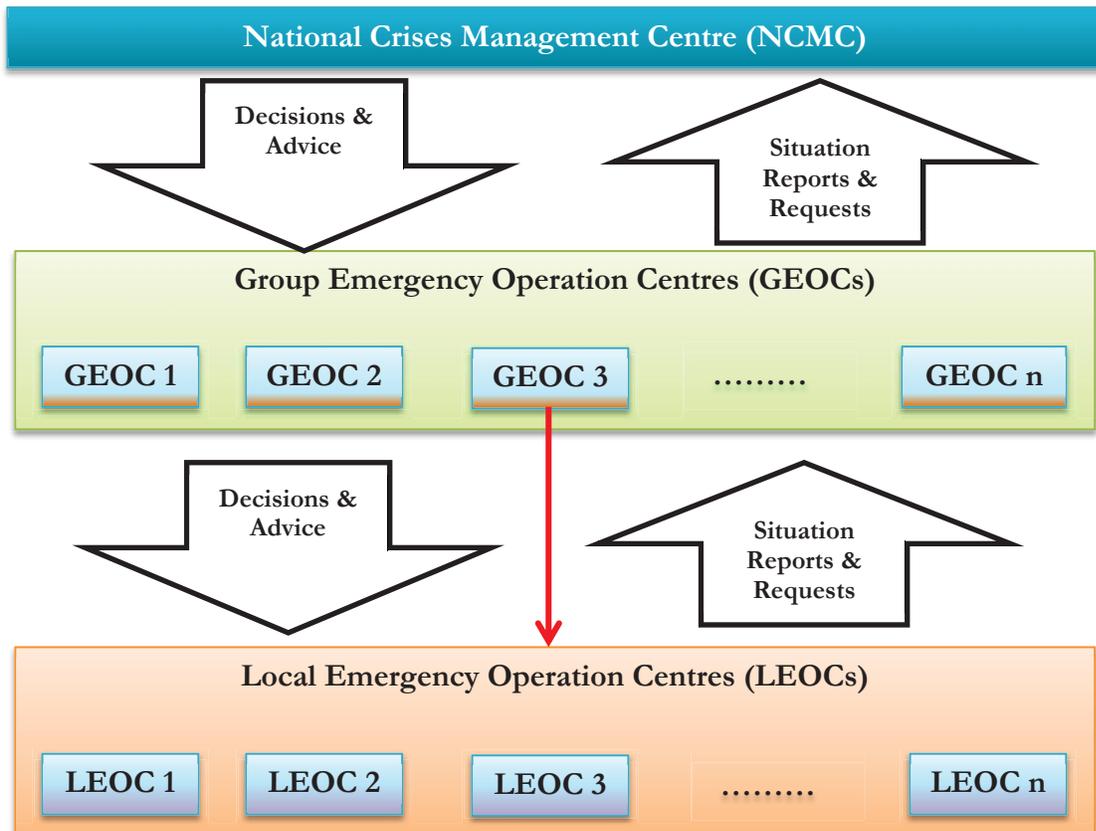
### **6.4.1 SSA and TSA requirements elicitation**

Information requirements for various roles of emergency managers have been identified in Chapter 4 using a cognitive task analysis technique, Extended Goal Directed Information Analysis. Although these information requirements were gathered for supporting an individual's SA, some additional information was also collected like the possible sources of information and where the processed information will go etc. Therefore, by keeping the definitions of SSA and TSA in view, information flows between the team members can be analysed to identify the SSA and TSA requirements.

#### ***6.4.1.1 SSA and TSA in Group Emergency Operation Centres (GEOCs)***

As discussed earlier in Chapter 2, this thesis considers Co-ordinated Incident Management System (CIMS) as a team architecture since it is used by emergency organisations in New Zealand for managing the response to an incident involving multiple agencies. The five basic functions of CIMS are Controller, Planning & Intelligence (P & I), Operations, Logistics and Welfare. In all emergency operation centres, including the National Crisis Management Centre (NCCMC), Group Emergency

Operation Centres (GEOCs) or Local Emergency Operation Centres (LEOCs), these functions exist either in the form of sub-teams or individuals depending upon their scale of responsibilities. All centres co-ordinate situation and collaborative tasks according to their roles and responsibilities. Therefore, SSA and TSA are required at different levels. Figure 6.2 shows the generic information flow and co-ordination needed to carry out the collaborative tasks and decision making during an emergency event.



**Figure 6.2 Coordination between NCMC, GEOC, and LEOC**

Within NCMC, GEOC, and LEOC, the structure of CIMS defines the responsibilities associated with each role. These responsibilities and tasks provide the basis for standardising the communication channels and information flows. Moreover, this classification of responsibilities and their respective requirements provide the framework for understanding where SSA and TSA are needed in the emergency operations. Figure 6.3 shows the CIMS structure within NCMC, GEOCs and LEOCs and an overview of the respective responsibilities of various roles within the functions.

In Figure 6.3, SSA and TSA in the GEOC are required in almost every process where there is more than one individual. For instance, within the P & I function, the situation

reporting section gathers data from various sources and discusses the technical and scientific analysis with qualified scientists in the Scientific Advisory Group (SAG). As a result, their SA is updated and they develop and share a common understanding (TSA) of the situation before reporting it in their situation report (SitRep).

In the case of a tsunami scenario, at the first “pre-confirmation of tsunami” phase (see Chapter 4), SAG guides the Situation Reporting function about the possibility of tsunami generation after analysing the earthquake parameters and other historic data.

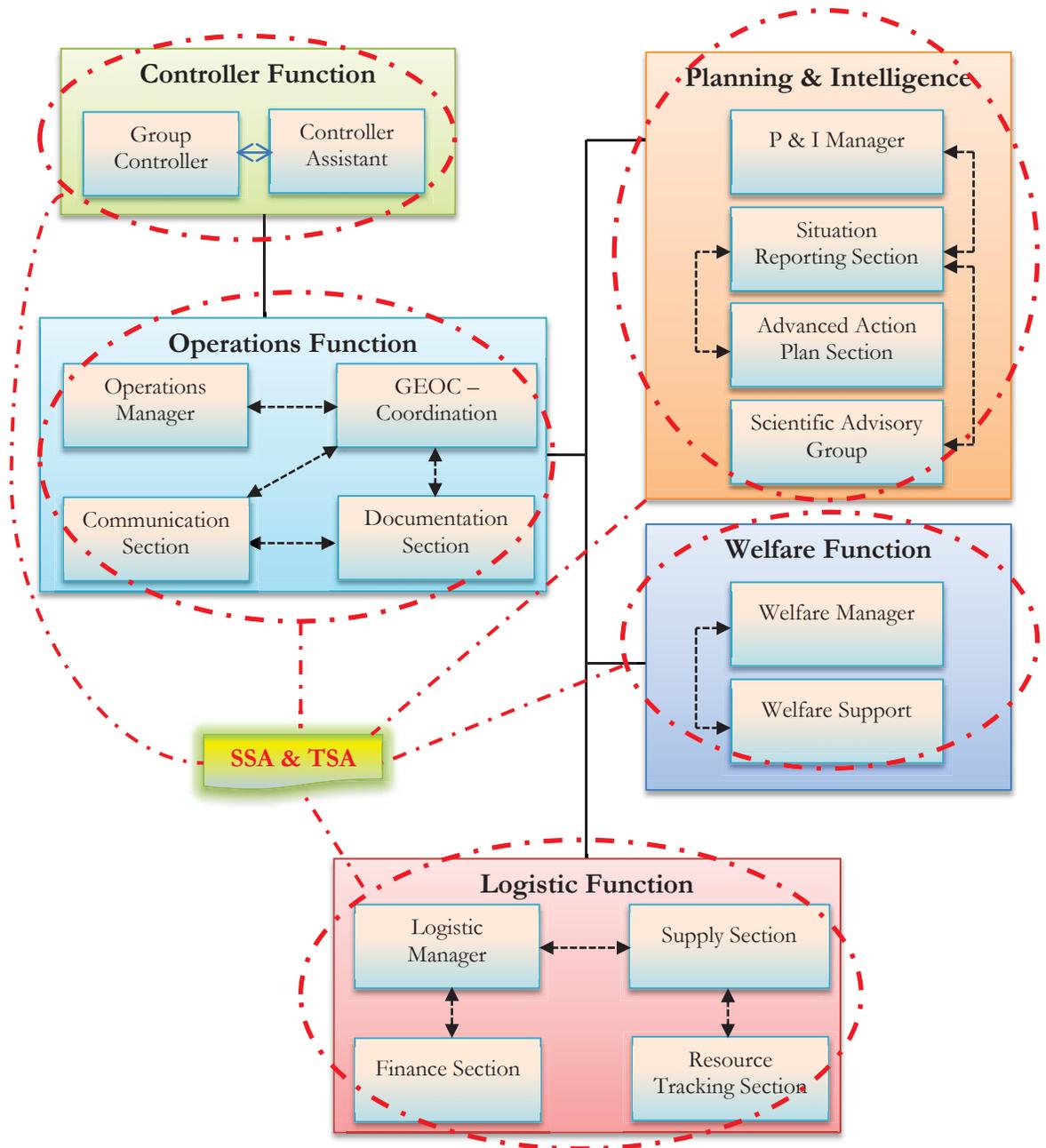


Figure 6.3 Example of Shared and Team Situation Awareness in GECC

The common or shared understanding of the situation is then passed to the Controller function so that more people share the understanding. Once the threat is confirmed, the Controller approves the full scale activation of the GEOC. The Controller also approves the SitRep or recommends changes before sharing it with other functions inside the GEOC or outside, e.g. with other GEOCs or NCMC. These other functions of GEOC, e.g. Operations, Logistics, and Welfare then take appropriate planning steps depending upon their responsibilities and their understanding of the SitRep.

Once a tsunami is confirmed, areas under risk are identified along with the arrival time of initial tsunami waves with the help of SAG and computer based simulations. The whole team of functions is taken on board to decide the evacuation plan depending on the available resources, i.e. human resources, transport, welfare camps etc. SSA and TSA are developed in terms of understanding the situation and the division of responsibilities. Depending upon the outcome of the evacuation decision, an Incident Action Plan (IAP) is developed by the Planning section of the P & I function. The IAP is discussed with the Situation Reporting section and the P & I manager to develop the needed level of SSA and TSA. Once approved by the Controller and NCMC, the IAP is shared within the GEOCs and LEOCs for action. During the implementation of the IAP, SSA is required to co-ordinate the activities within GEOCs and outside, e.g. with NCMC, concerned LEOCs, Police, Fire Service, NGOs and other Lifeline organizations. By extending the required co-ordination and collaboration, these organisations can be considered as a team of teams having certain aspects of SSA and TSA needed to achieve the common goal of successful mass evacuation as shown in Figure 6.4. The organisations mentioned here are just examples since dozens of organisations can be involved in a mass evacuation depending upon its scale.

#### ***6.4.1.2 SSA and TSA information requirements***

Based on SA oriented design principles (Endsley et al., 2003) the following considerations are relevant to the design of SSA and TSA oriented system:

1. Avoid information overload in shared displays
2. Provide flexibility to support shared SA across tasks and team members
3. Support communication of comprehensions and projections across teams
4. Standardisation of information flows and formats

5. Support transmission of SA within positions by making status of elements and states explicit
6. Proactive sharing of information to save time
7. Sharing SA of team members as and if required by other team members instead of broadcasting

These design principles, and the design aspects previously described in Chapters 4 and 5 are used to extend SAVER's functionality to support SSA and TSA. In addition, information required by the team members is also shared according to their contexts and requirements. Tables 6.1-6.3 show some example GEOC roles to illustrate the SSA requirements at different levels.

**Table 6.1 SSA Level 1 requirement of Situation Reporting Section (P&I)**

<b>SSA Requirement Template</b>	
<b>SSA requirement identifier</b>	SSAL1G1T1I1
<b>SA Level</b>	SSA Level 1
<b>Goal Identifier</b>	G1
<b>Goal</b>	Report current situation to the stakeholders
<b>Task Identifier</b>	T1
<b>Task</b>	Develop SitRep
<b>Information requirement identifier</b>	I1
<b>Information requirement</b>	Magnitude, Source depth, Source coordinates, Time
<b>Source (Priority)</b>	US Geological Survey (USGS) report on earthquake (1)
<b>Destination</b>	Situation Reporting (P & I)

The Level 1 SSA information requirement in Table 6.1 can be automatically fulfilled by SAVER, since it can be acquired from the USGS website and reported to the managers performing situation reporting. Similarly, Table 6.2. provides an example of the Level 3 SSA information requirement.

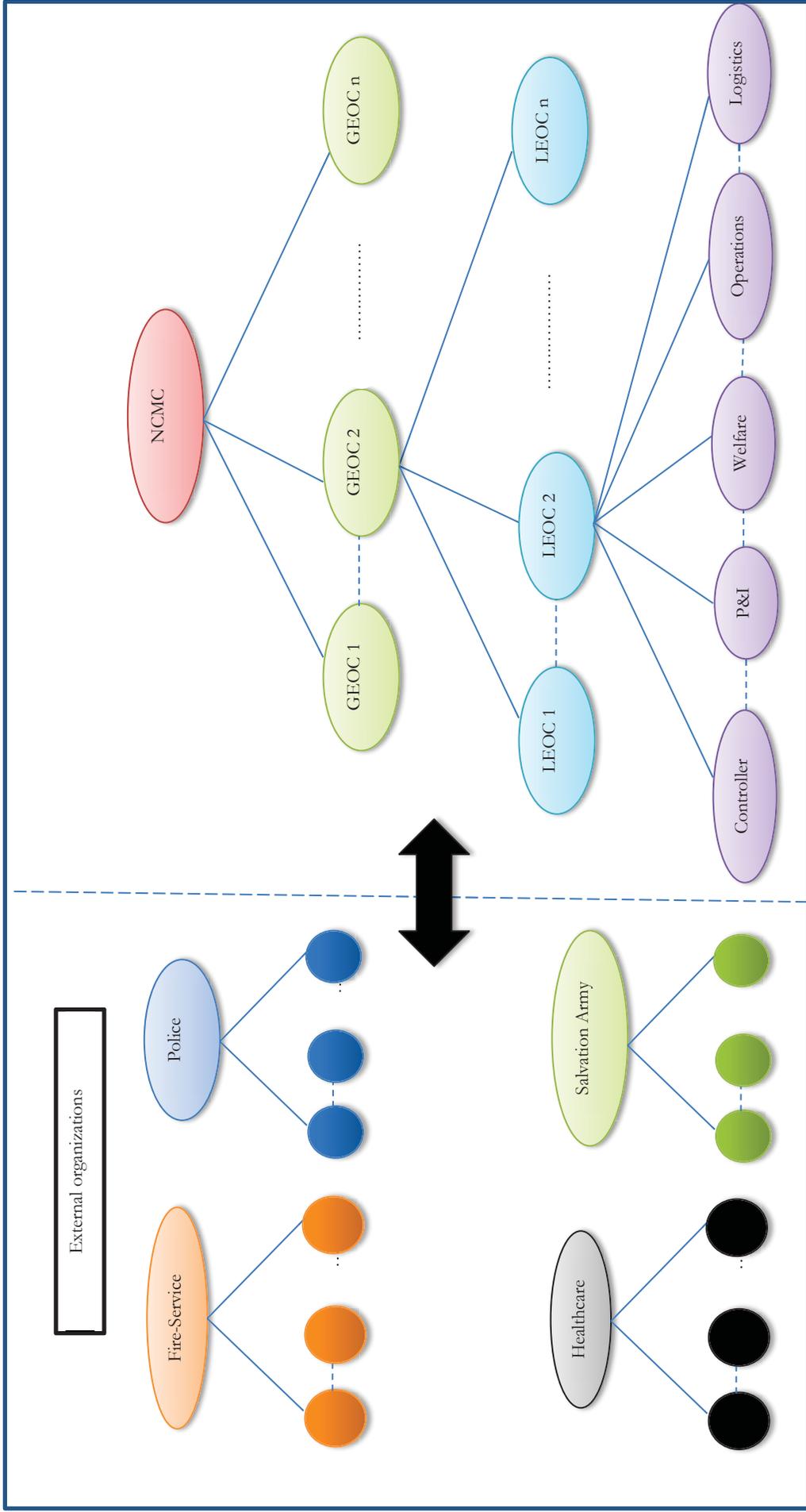


Figure 6.4 Team of teams involved in mass evacuation

**Table 6.2 SSA Level 3 requirement of Situation Reporting Section (P & I)**

SSA Requirement Template	
SSA requirement identifier	SSAL3G1T1I4
SA Level	SSA Level 3
Goal Identifier	G1
Goal	Report current situation to the stakeholders
Task Identifier	T1
Task	Develop SitRep
Information requirement identifier	I4
Information requirement	Areas marked for evacuation
Source (Priority)	Scientific Advisory Group (SAG) (1), USGS (2)
Destination	Situation Reporting (P & I)

Templates provided in Tables 6.1 and 6.2 are used to gather the SSA requirements for each level. SAVER has an information requirements broker designed to prompt team members about the information needs of their colleagues. When information requirements cannot be automatically fulfilled by SAVER, an alert is generated for manual input.

However, instead of dictating the process, SAVER guides the situation assessment and the final decision is left for human decision makers. Users can agree or disagree with SAVER's suggestions and the system shares the degree of agreement or disagreement with relevant people so that team members can see other's views along with the suggestions. In this way, team members' beliefs about other's understanding are also updated to improve TSA (Shu and Furuta, 2005). These features require information about the team members who share common goals, tasks and decisions. This is crucial for sharing the explicit situation assessment by SAVER and the SA of the fellow team members. Table 6.3 provides an example template of the information requirement of TSA.

**Table 6.3 TSA Level 2 Requirement of Situation Reporting (P & I)**

TSA Requirement Template	
TSA requirement identifier	TSAL2G1T4I8
SA Level	TSA Level 2
Goal Identifier	G1
Goal	Report current situation to the stakeholders

<b>Task Identifier</b>	T4
<b>Task</b>	SitRep Development
<b>Information requirement identifier</b>	I8
<b>Information requirement</b>	Tsunami generation confirmation
<b>SA Source role</b>	Scientific Advisory Group (SAG)
<b>SA Destination role(s)</b>	Situation Reporting, P & I Manager, Controller

Table 6.3 shows a situation assessed by the SAG (SA source) that needs to be shared with Situation Reporting, the P & I Manager and the Controller to develop a consensus on the prevailing situation. Hence, the SA of SAG members is shared with the destination roles to develop a common understanding and improve belief about team members' understanding.

## 6.4.2 Ontology based SSA and TSA oriented system design

### 6.4.2.1 Ontology-based information requirements and SA broker

The information requirements broker works using ontologies. Since information, requirements of individual roles are already present in the form of ontologies (Chapter 4), it is easy to re-use them for SSA and TSA. Ontology-based context modelling (Chapter 5) makes the ontology-based information broker an ideal candidate to route information requirements to the team member who can fulfil them whilst offering seamless interaction with the rest of the SAVER architecture. Information about the source of each requirement is added according to its priority so that if the required information is not available from one source, SAVER can look for the information elsewhere. In this way, SAVER either supplies the required information from its knowledge base or prompts for manual input. SAVER also has a chat client that can be used to contact other team members.

SAVER uses the following steps to perform information brokerage and improve SSA:

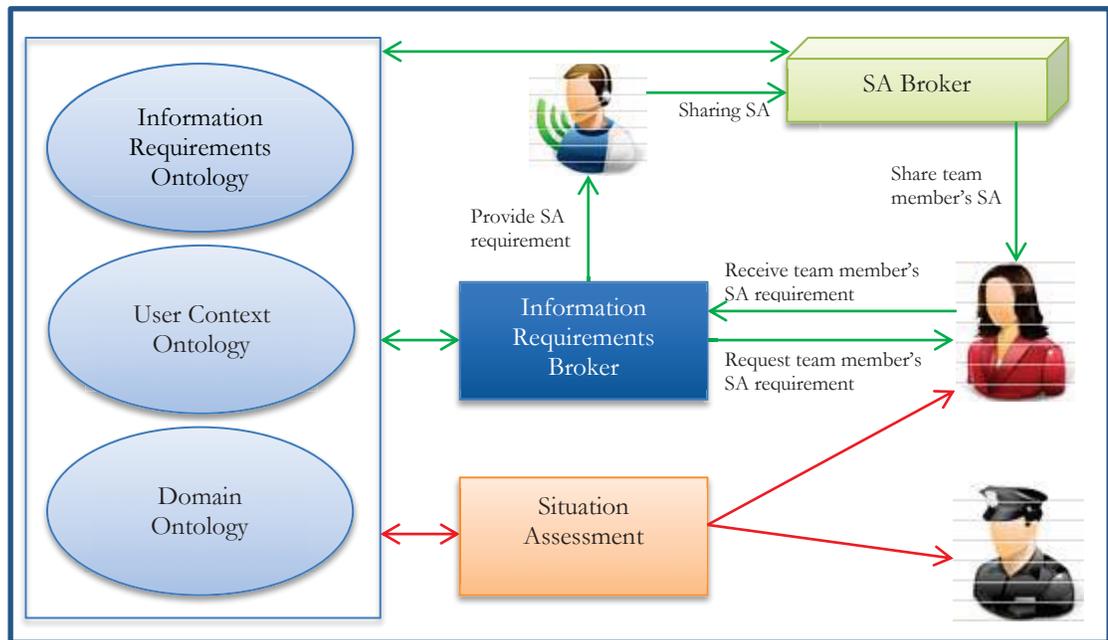
1. Identify a user's information requirements using their context information (discussed in Chapter 5)
2. Identify the common information requirements (information requirements linked to more than one role in ontologies)
3. Identify the sender (source) and receiver of each information requirement

4. Send the required information or request sender to send the required information
5. Route the response from sender to receiver

SAVER uses the following steps to perform information brokerage for improving TSA:

1. Share the explicit situation assessment with users according to their requirements (improves common understanding of the situation)
2. Share a team member's understanding of the situation with other team members (improves common understanding and belief about other team members' SA)
3. Provide the information required for every team member's SA needed to fulfil his/her responsibilities (improves individual SA and hence the overall TSA)

Figure 6.5 shows the system architecture of this module of SAVER to improve the SSA and TSA of the emergency managers.



**Figure 6.5 SAVER architecture to support SSA and TSA**

As shown in Figure 6.5, SAVER's architecture is extended to accommodate the support for SSA and TSA by adding the feature to share information between the team members. The information requirements broker uses an ontology-based reasoner (Fact++) to find which information to share with whom on the basis of user context features, e.g. role, common goals, tasks and information requirements. Similarly, an SA

broker uses an ontology reasoner for identifying whose SA should be shared with whom, depending upon their roles, SA requirements, common tasks and decisions.

Existing ontologies of information requirements and user's context are re-used as shown in the partial example ontology in Figure 6.6. *Planning&Intelligence*, and *Operations* are the roles (context information) and *NCMC\_warnings*, *LEOC\_sitrep* and *area\_to\_evacuate* are the information requirements. *ScientificAdvisoryGroup* (role) is the sender or *InformationRequirementSource* of *area\_to\_evacuate* and *Operations* is *InformationRequirementSource* of *NCMC\_warnings* and *LEOC\_sitrep*. Information requirement, e.g. *area\_to\_evacuate* is shared using the other context information like *DecisionPhase*. *NCMC\_warning*, *LEOC\_sitrep*, *area\_to\_evacuate* are individuals of class (Concept) type *InformationRequirement* whereas *hasSource*, *hasInformationRequirements* and *during* are object properties showing relationships between the concepts.

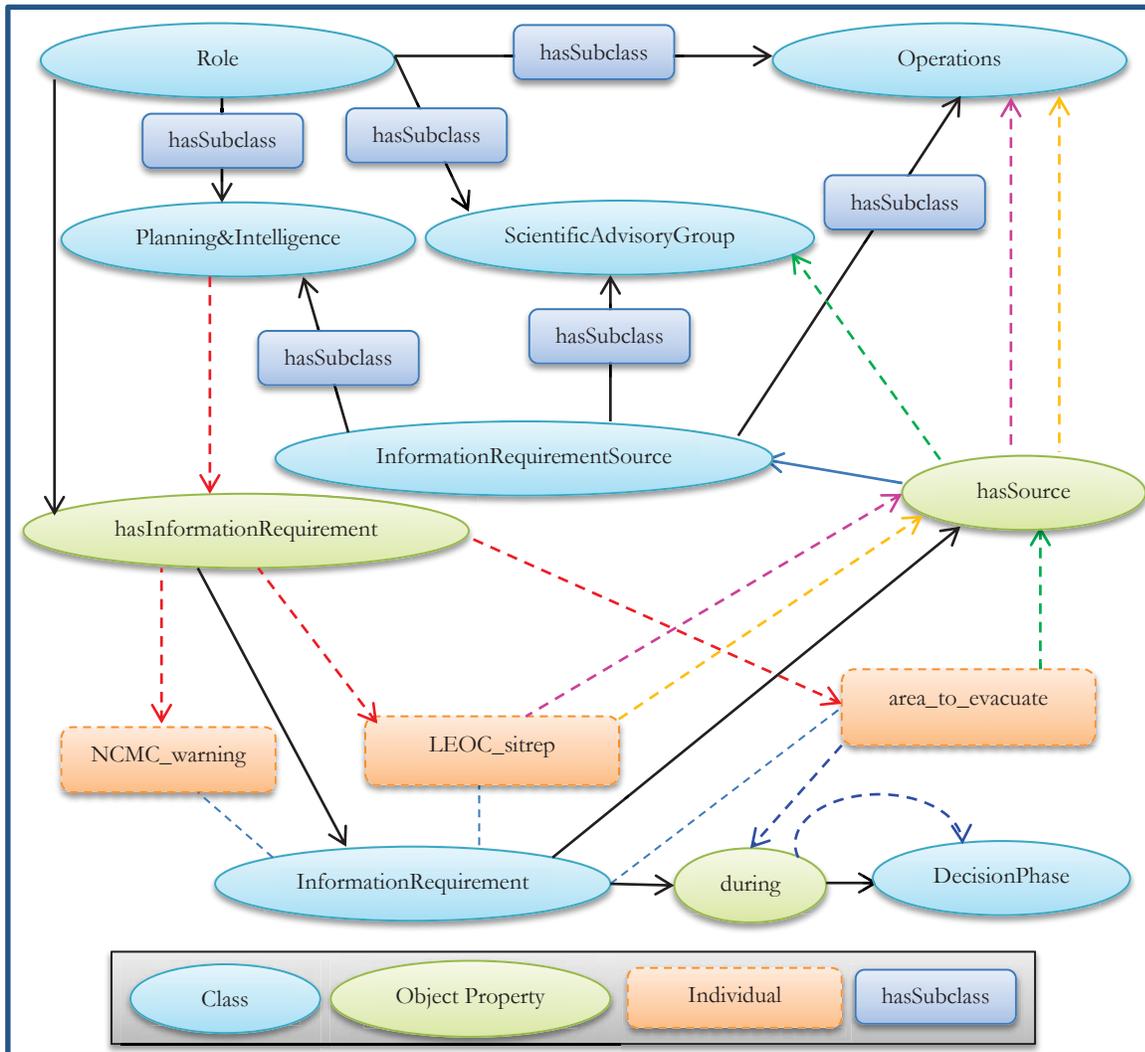


Figure 6.6 Partial example ontology for TSA and SSA support

#### 6.4.2.2 SAVER User interface features for SSA and TSA support

**Explicit situation assessment for common awareness:** To support the common awareness required for TSA, SAVER provides the explicit situation analysis with logical arguments (situation assessment provided in Chapter 5), and providing the reasoning with the situation assessment updates the user’s SA. In other words, it promotes a true and common understanding of the situation amongst the decision makers. Figure 6.7 shows a SAVER screen shot that demonstrates explicit situation assessment.



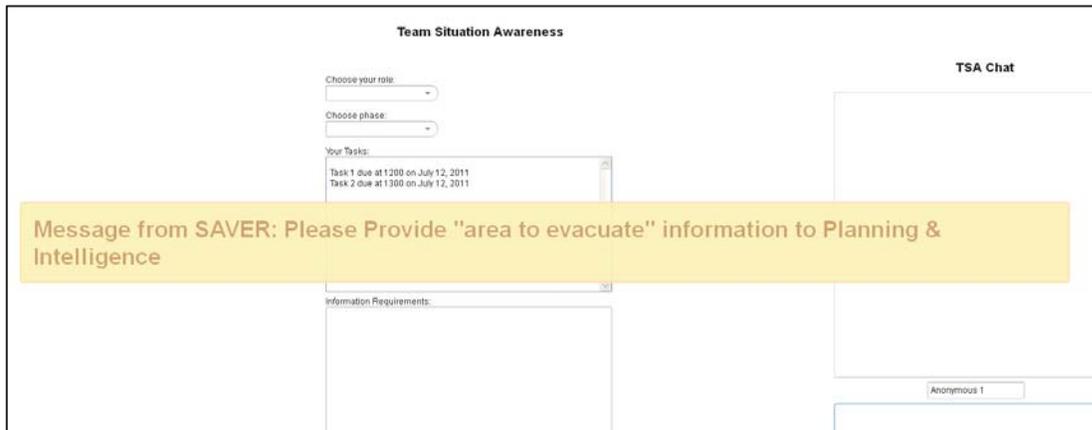
Figure 6.7 Explicit situation assessment provided by SAVER

**Sharing a team member’s SA for common awareness:** Moreover, if the user has a conflict over the situation assessment, they can make their argument in the chat window to let others know their opinion. Otherwise, by simply selecting “Agree” and pressing the “Submit” button, their SA is shared with other relevant team members. Figure 6.8 shows an example message that relevant team members might receive. This message will appear on their screen for a few seconds and then disappears but it can be viewed at any time in the shared SA report box as shown in Figure 6.8.



**Figure 6.8 Example message from SAVER about team member's SA**

**Sharing a team member's SA requirements to support SSA:** SAVER provides the information about the SA requirements of the team members where manual input is required from the other team members. In this case, it asks for the desired information proactively on behalf of the person who needs it, for example, see Figure 6.9.



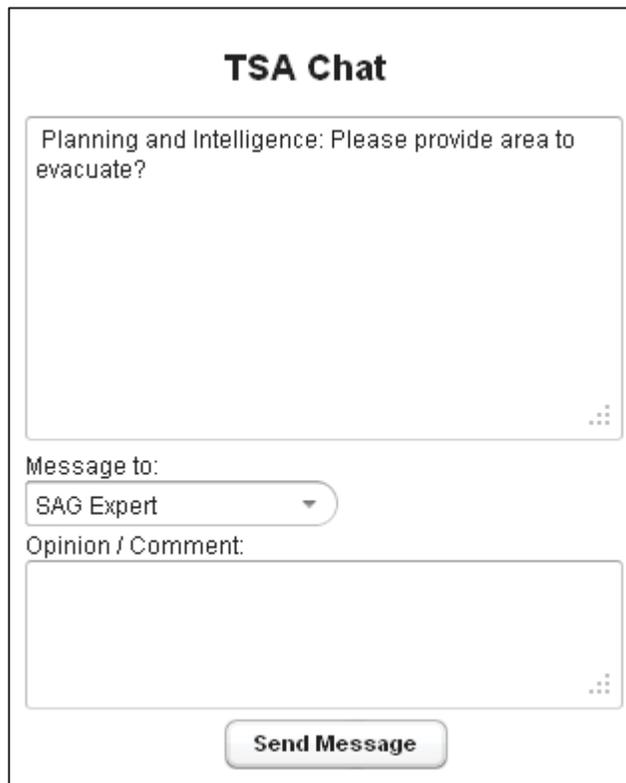
**Figure 6.9 Example message from SAVER asking for information**

Similarly, SAVER shares the information about the SA requirements automatically, if possible. For example, Figure 6.10 shows an alert from LEOC 1 that a new SitRep has arrived with update information.



**Figure 6.10 Example message from SAVER about new information**

**Chat client to support SSA and TSA:** If further clarification is needed from another team member on any matter, e.g. information requirement or situation assessment, the chat client can be used. It allows messages to specific team members or a general broadcast. Moreover, it can be used to share additional information on situation assessment or a disagreement. Figure 6.11 shows an example message in a chat box.



**Figure 6.11 Example chat client for communication**

## 6.5 Evaluation

Since this module of SAVER is intended to improve the SSA and TSA of a team, it is evaluated by the direct measurement of SSA and TSA of SAVER users. The shared and team SA measurement methodology is based on SAGAT (as discussed in Chapter 5) by modifying it according to the requirement of Shared SA and team SA measurement.

SSA and TSA queries were presented to the participants in the same experiments performed to measure individual SA (Chapter 5). An SSA and TSA queries pool was developed by using Endsley's definitions of SSA (Endsley & Jones, 2001), the mutual belief model of TSA (Nonose et al., 2010; Shu & Furuta, 2005), and the definition of TSA due to Salas et al., (1995).

Our evaluation method builds upon the shared SA outcomes identified by Jones and Endsley (2002), from which we propose a similarity measure that calculates the degree of SA shared between two team members. TSA is evaluated by directly comparing any two given team members with regard to the similarity of their understanding of the situation elements that are relevant to both of them. Similarly, SSA is measured by comparing their answers about the common SA requirements.

### 6.5.1 Experiment design

#### *6.5.1.1 Instrument and scenario*

A few additional queries about the SSA and TSA were asked in the same experiments carried out to measure individual SA as discussed in Chapter 5. For detailed evaluation, SSA and TSA were measured at all three levels so the queries were designed for these levels as discussed in the previous section. Participants were queried about their own and team member's SA requirements. Example SSA queries are shown in Table 6.4.

In Table 6.4, the participants are asked about their own SA requirements on all three levels. The participants are then asked about their team members' information requirements. For the experiments without SAVER, "SAVER" was not considered as a valid answer to a query and is not shown in the answer options in Table 6.4.

One of the frameworks to measure team SA (TSA) is based on the team cognition and mutual belief model (Nonose et al., 2010; Shu & Furuta, 2005, Kano, 2007). The model is composed of three layers of mental components, which represent the structure of mutual belief in team cognition. The first layer represents an individual's cognition, the

second layer represents beliefs in a partner's cognition, and the third layer represents a belief in a partner's belief (Nonose et al., 2010). Assuming there is a team of two members A and B, the model is described as:

$M_a = A$ 's cognition,  $M_b = B$ 's cognition

$M_a' = A$ 's belief about  $M_b$ ,  $M_b' = B$ 's belief about  $M_a$

$M_a'' = A$ 's belief about  $M_b'$ ,  $M_b'' = B$ 's belief about  $M_a'$

Where in the last line the double index terms can be written:

Where  $M_a''$  means A's belief about what B believes about A

And  $M_b''$  means B's belief about what A believes about B

Team SA evaluation is based on the degree of agreement on these beliefs and cognitions. For example, matching A's cognition of the situation with B's belief about A's cognition can give a complete picture of team SA. Though the model proposed by Nonose et al. (2010) seem promising, they used a subjective approach to gather the data by asking subjects to rate their own SA. However, the subject's belief about his/her own SA can be different from his/her actual SA.

**Table: 6.4 Example SSA queries at own and team member's requirements**

SSA Level	Target	Questions	Possible answers	SSA Level	Target	Questions	Possible answers
1	Own SA 1 requirement	What information elements do you think are relevant in the current situation?	Earthquake magnitude, Source location, Source Depth	1	Team member's SA 1 requirement	What information elements do you think are relevant to your team member's role?	Earthquake magnitude, Source location, Source Depth
1	Own SA 1 requirement	What information cues did you perceived were relevant to the tsunami generation?	Earthquake magnitude, Source location, Source Depth	1	Team member's SA 1 requirement	What information cues did your team member perceive as relevant to tsunami generation?	Earthquake magnitude, Source location, Source Depth
2	Own SA 2 requirement	What did you require to understand / interpret the perceived cues? Please list sources	Knowledge of tsunami generation, Experience, communication, other	2	Team member's SA 2 requirement	What did your team member require to understand / interpret the perceived cues? Please list sources	Knowledge of tsunami generation, Experience, communication, other
2	Own SA 2 requirement	What have you used to understand or interpret the perceived information? Rank by putting a number	Experience, SAVER, communication, other	2	Team member's SA 2 requirement	What has your team member used to understand or interpret the perceived information? Rank by putting a number	Experience, SAVER, communication, other
3	Own SA 3 requirement	What information did you need to predict the tsunami generation? Please list sources	Knowledge of tsunami generation, Experience, communication, other	3	Team member's SA 3 requirement	What information did your team member need to predict the tsunami generation? Please list sources	Knowledge of tsunami generation, Experience, communication, other
3	Own SA 3 requirement	What have you used to predict the perceived information? Rank by putting a number	Experience, SAVER, communication, other	3	Team member's SA 3 requirement	What has your team member used to predict the tsunami generation? Rank by putting a number	Experience, SAVER, communication, other

Therefore, this approach is error prone, and we extended it by objective SA measurements observing the direct performance of users to see what they themselves know and what they know about their team members. Likewise, beliefs about the team members are elicited from direct questions about the team member's SA. We believe that by using the objective approach we can get a more accurate picture of team SA. Table 6.5 shows the example questions for measuring TSA.

**Table: 6.5 Example TSA queries**

<b>TSA Level</b>	<b>Target</b>	<b>Questions</b>	<b>Possible Answers</b>
1	TSA 1: Belief about team member's cognition	What do you think your team member answered about magnitude, depth and location of earthquake?	8.1 28km 15.0 W 115.0 N
1	TSA 1: Team member's belief about own belief	What do you think your team member believed about your answers to magnitude, depth and location of earthquake?	8.1 28km 15.0 W 115.0 N
2	TSA 2: Belief about team member's cognition	What do you believe about how your team member will rate magnitude	High enough, Very high
2	TSA 2: Team member's belief about own belief	What do you think your team member believed about your rating of magnitude?	High Enough. Very high
2	TSA 2: Belief about team member's cognition	According to your belief, what is your team member's understanding of source depth and earthquake source location to generate a tsunami?	Likely, Highly likely
2	TSA 2: Team member's belief about own belief	What do you think your team member believed about your understanding of source depth and earthquake source location to generate a tsunami?	Likely, Highly likely
3	TSA 3: Belief about team member's cognition	According to your belief what is your team member's prediction about the likelihood of tsunami generation?	Likely, Highly likely
3	TSA 3: Team member's belief about own belief	What do you think your team member's believe about your prediction of tsunami generation?	Likely, Highly likely

Questions about own cognition are not included in Table 6.6 since they are covered by measuring an individual's SA in Chapter 5.

For measurement of TSA according to the Salas et al. (1995) definition, answers of each team member to SA measurement questions used in Chapter 5 are compared with the team member's answers and one point is awarded to correct matching answers otherwise 0 is given. To measure TSA according to Endsley and Jones (2001) definition the SA measures of both team members' (Chapter 5) are aggregated.

### 6.5.1.2 Participants

The detail of participants has been provided in section 5.5.1.4 of Chapter 5. Emergency managers were randomly grouped into eight teams of two, as described in Table 6.6.

**Table 6.6 Distribution of participants in teams**

Participant (Identifier)	Team (Identifier)	Participant Team Identifier
P1	T1	P1T1
P2	T1	P2T1
P3	T2	P3T2
P4	T2	P4T2
P5	T3	P5T3
P6	T3	P6T3
P7	T4	P7T4
P8	T4	P8T4
P9	T5	P9T5
P10	T5	P10T5
P11	T6	P11T6
P12	T6	P12T7
P13	T7	P13T7
P14	T7	P14T7
P15	T8	P15T8
P16	T8	P16T8

Participants are assigned unique identifiers for easy identification by combining their participant and team identifiers as shown.

## 6.5.2 Experiment results

### 6.5.2.1 Data analysis method

Figure 6.12 illustrates the data analysis method for SSA data. As in previous analyses, marks of 0 and 1 are respectively assigned to incorrect and correct answer to queries. Thus, the marks for example questions 1, 2 and 3 targeted at SSA Level 1 are added to generate the SSA Level 1 score of participant 1. Similarly, questions 4 and 5 are combined to generate an SSA Level 2 score and questions 6 and 7 are combined to generate an SSA

Level 3 score for participants 2 and 3 respectively. An overall SSA score for each participant is created by aggregating the marks for all questions targeted at SSA, e.g. the SSA score for participant 4 in Figure 6.12 is the sum of the combined scores for questions 1 to 7.

To generate a team's SSA, the scores of team members are averaged. For example, for the data in Figure 6.12, team B's SSA score is the average of the scores for participants 3 and 4.

All scores calculated as described can be converted to percentages by dividing each score by the total number of questions asked at the appropriate level, or asked in total for a team, and multiplying by 100.

SSA Level	Participant 1 <del>Team A</del>	Participant 2 Team A	Participant 3 Team B	Participant 4 Team B
SSA1	Question 1	Question 1	Question 1	Question 1
SSA1	Question 2	Question 2	Question 2	Question 2
SSA1	Question 3	Question 3	Question 3	Question 3
SSA2	Question 4	Question 4	Question 4	Question 4
SSA2	Question 5	Question 5	Question 5	Question 5
SSA3	Question 6	Question 6	Question 6	Question 6
SSA3	Question 7	Question 7	Question 7	Question 7

SSA 1 score of  
Participant 1

SSA 2 score of  
Participant 2

SSA 3 score of  
Participant 3

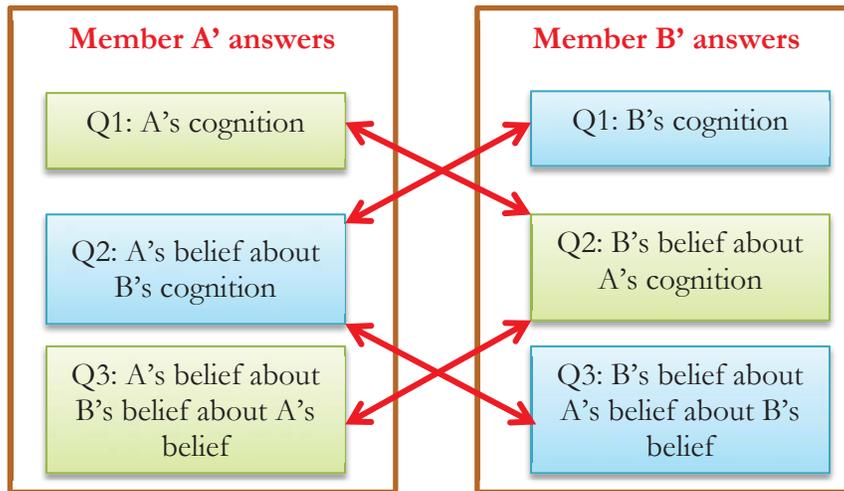
SSA score of  
Participant 4

**Figure 6.12 Distribution of example questions and result analysis method**

Similar measurements and analyses are made for TSA.

For the belief model of Shu and Furuta (2005), TSA questions are combined according to the TSA levels and averaged to generate the score for each individual as shown for SSA in Figure 6.12. A Team's TSA score for this model is the average of both team members' overall TSA score similar to the SSA example or participant 4 in Figure 6.12.

Figure 6.13 shows an example for the belief model. In Figure 6.13 the answer to question Q2 for Member A will be considered correct only if it matches the answer of Q1 for member B and vice versa.

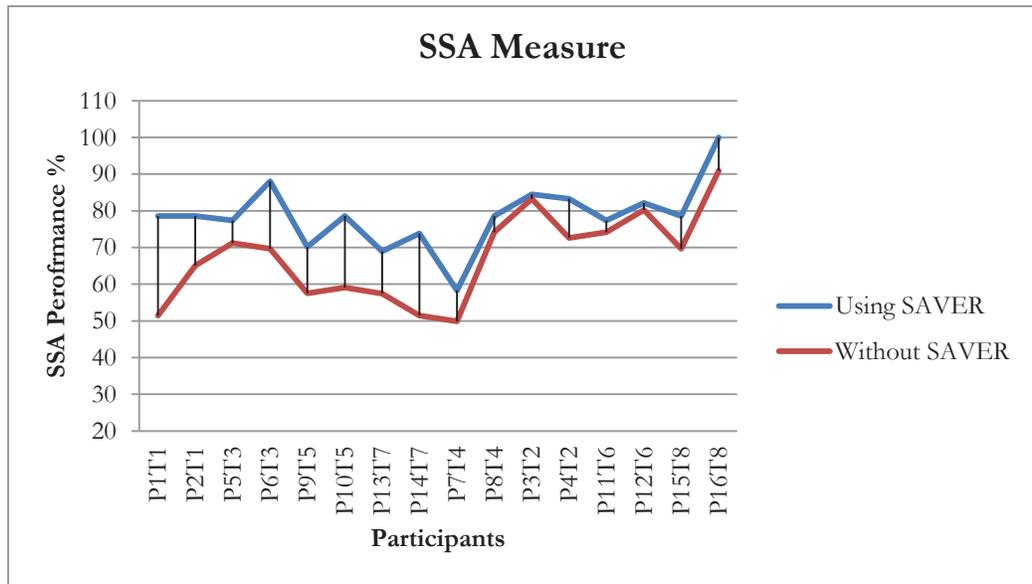


**Figure 6.13 Shu and Furuta (2005)'s belief model**

The common understanding of the situation is measured by comparing the answers used in the measurement of the individual's SA in Chapter 5. Therefore, the team SA score will simply be the average of the similar correct answers. The team SA score according to Endsley's model is generated by combining and averaging the individual SA score of the participants.

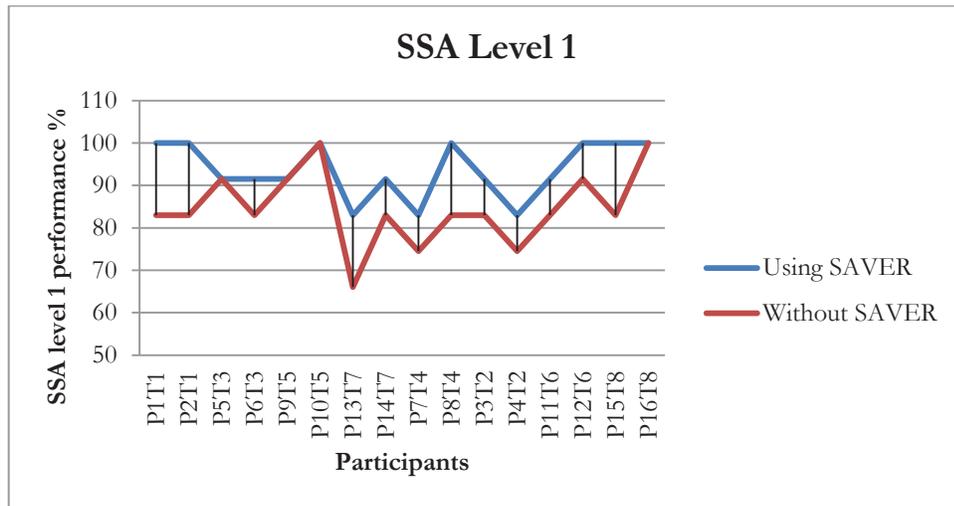
#### **6.5.2.2 SSA Measurements with and without SAVER**

The results of the SSA measurements (see Figure 6.14) show the overall SSA scores of every individual. Participants who used SAVER performed very well compared with those who did not use it. A paired sample T-test showed a significant difference ( $t = 5.95$ ,  $p\text{-value} < 0.001$ ) between the scores of each participant without SAVER ( $M=67.3$ ,  $S.D=12.1$ ) and using SAVER ( $M=78.5$ ,  $S.D=9.0$ ).



**Figure 6.14 SSA measures with and without SAVER**

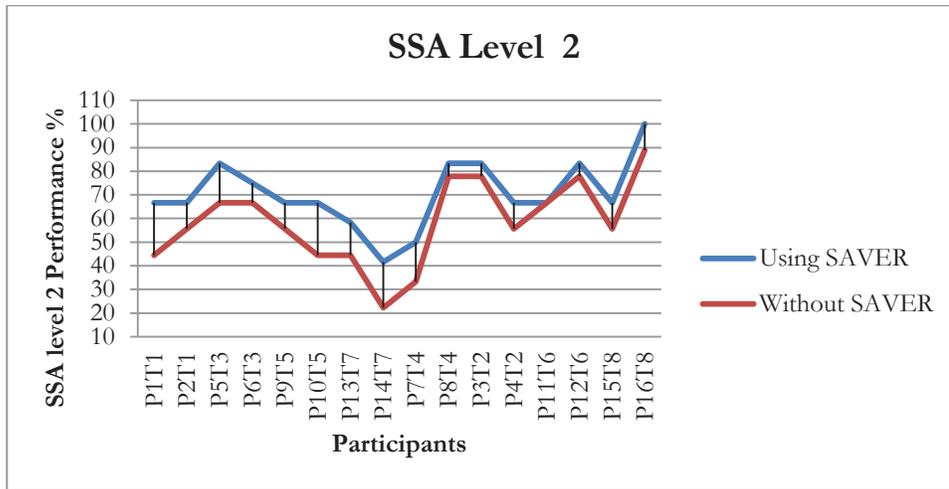
Results are further broken down into the three levels of SSA. Figure 6.15 presents the Level 1 SSA results for each individual.



**Figure 6.15 SSA Level 1 measures with and without SAVER**

The result of measuring Level 1 SSA using and without using SAVER shows an improved performance by those who were using SAVER during the experiment. A paired sample T-test shows a significant difference ( $t = 5.50$ ,  $p\text{-value} < 0.001$ ) between the scores of participants using SAVER ( $M=93.6$ ,  $S.D=6.5$ ) and for individuals not using SAVER ( $M=84.6$ ,  $S.D=8.9$ ).

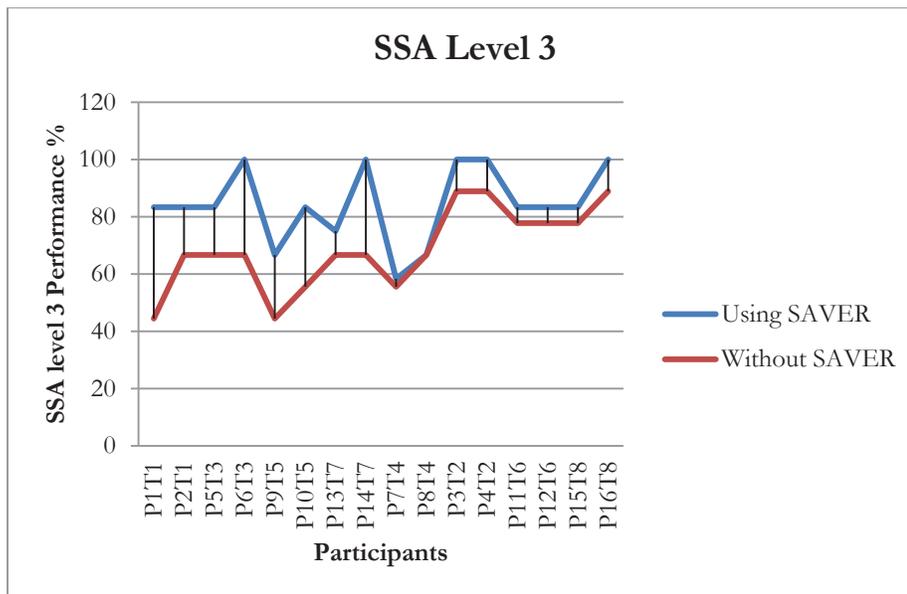
Figure 6.16 presents the Level 2 results for individuals.



**Figure 6.16 SSA Level 2 measures with and without SAVER**

Figure 6.16 shows the results of measuring Level 2 SSA with and without SAVER. The results show that use of SAVER also improves SSA Level 2. A paired sample T-test shows a significant difference ( $t = 7.5$ ,  $p\text{-value} < 0.001$ ) in the score of the participants not using SAVER ( $M=58.3$ ,  $S.D=17.9$ ) and the score for using SAVER ( $M=70.3$ ,  $S.D=14.2$ ).

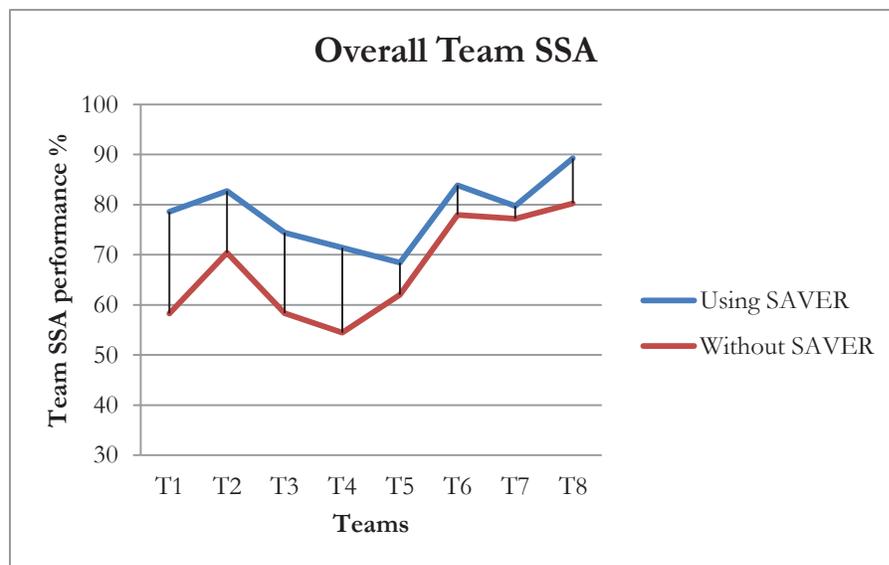
Figure 6.17 presents the Level 3 SA results for individuals.



**Figure 6.17 SSA Level 3 measures with and without SAVER**

Figure 6.17 shows the results of measuring SSA level 3 with and without SAVER. The results show that SAVER improves SSA at Level 3. A paired sample T-test confirms a significant difference ( $t = 5.17$ ,  $p\text{-value} < 0.001$ ) in the score of participants not using SAVER ( $M=68.7$ ,  $S.D=14.1$ ) and the score of participants using SAVER ( $M=84.3$ ,  $S.D=13.2$ ).

Figure 6.18 below shows the overall team's SSA with and without SAVER by aggregating and averaging the team member's scores. The results show that the combined performance of each team is much better when they were using SAVER than when they were not. The paired sample T-test shows a significant difference ( $t = 5.07$ ,  $p\text{-value} = 0.001$ ) found in the score of the participants not using SAVER ( $M=67.3$ ,  $S.D=10.31$ ) and the score of the participants using SAVER ( $M=78.5$ ,  $S.D=6.9$ ).

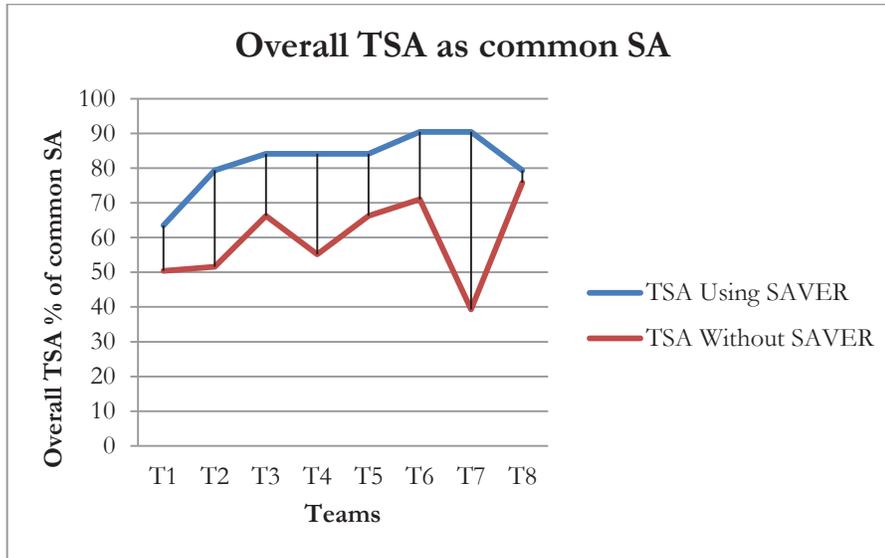


**Figure 6.18 Team SSA score with and without SAVER**

### ***6.5.2.3 TSA Measurement***

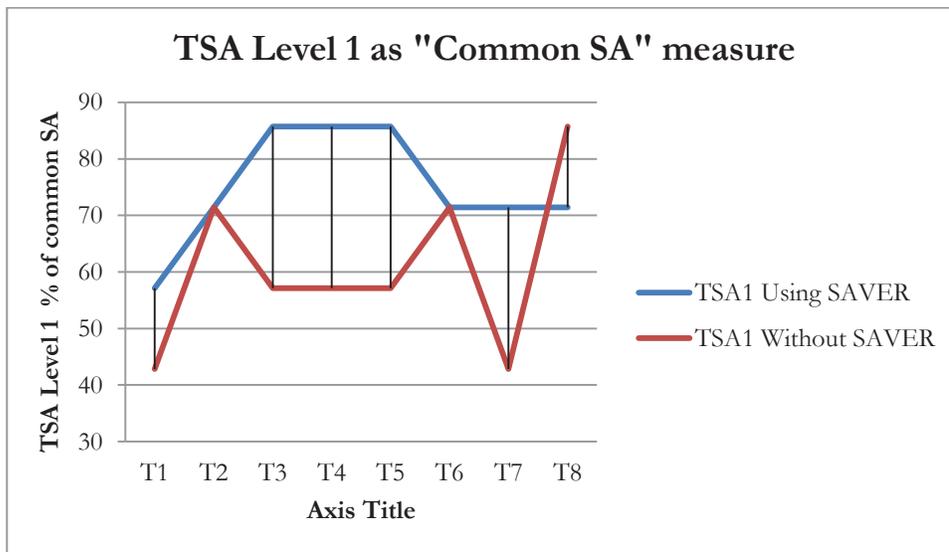
**TSA as “common SA” measure:** Considering the TSA as the degree to which team members share a similar understanding of the situation is measured by comparing their answers. The team whose correct answers match will get 1 and others get 0. Hence, the percentage of correct similar answers developed the common SA or TSA measure. The result of the TSA measurement for teams is shown in Figure 6.19. Substantial improvement in the score of a team that used SAVER during the experiments can be seen compared to those who did not. A paired sample T-test shows that there is a

significant difference ( $t = 4.50$ ,  $p\text{-value} = 0.003$ ) in the scores for not using SAVER ( $M=59.5$ ,  $SD=12.3$ ) and using SAVER ( $M=81.9$ ,  $D=8.6$ ).



**Figure 6.19 Overall TSA (as common SA) score with and without SAVER**

Results are further broken down into the three levels of TSA. Figure 6.20 presents the results for Level 1 TSA.

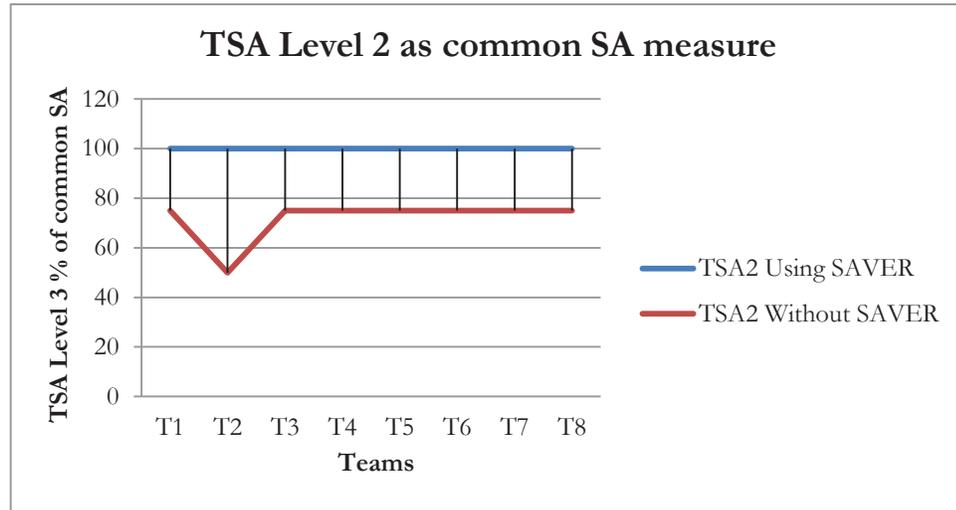


**Figure 6.20 TSA (as common SA) Level 1 measures with and without SAVER**

The result of measuring Level 1 TSA using and without using SAVER shows the team using SAVER has performed much better. A paired sample T-test shows that a

significant difference ( $t = 2.36$ ,  $p\text{-value} = 0.05$ ) in the score of the participants using SAVER ( $M=75.0$ ,  $S.D=10.1$ ) and the score without using SAVER ( $M=60.7$ ,  $S.D=14.8$ ).

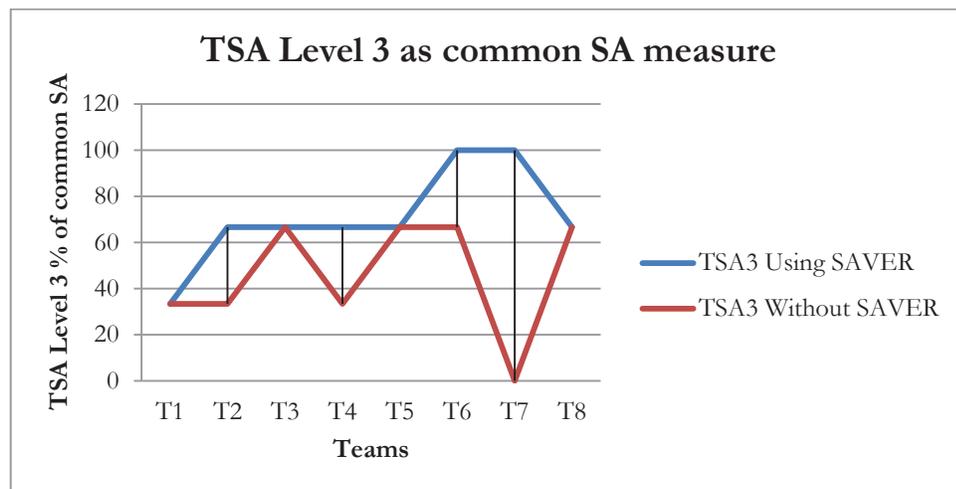
Figure 6.21 below presents the Level 2 TSA data for the teams.



**Figure 6.21 TSA (as common SA) Level 2 measures with and without SAVER**

Figure 6.21 shows the results of measuring Level 2 TSA with and without SAVER. The results show that TSA level 2 of teams using SAVER is 100%. A paired sample T-test shows a significant difference ( $t = 9.00$ ,  $p\text{-value} < 0.001$ ) in the score of the participants not using SAVER ( $M=71.9$ ,  $S.D=3.1$ ) and the score for using SAVER ( $M=100.0$ ,  $S.D=0.0$ ).

Figure 6.22 below presents level 3 TSA for the teams.



**Figure 6.22 TSA (as common SA) Level 3 measures with and without SAVER**

Figure 6.22 shows the results of measuring Level 3 TSA with and without SAVER. The result again shows that SAVER also improves the TSA at Level 3. A paired sample T-test shows a significant difference ( $t = 2.04$ ,  $p\text{-value} = 0.08$ ) in the score of the participants not using SAVER ( $M=45.8$ ,  $S.D=24.8$ ) and the score of the participants using SAVER ( $M=70.8$ ,  $S.D=21.3$ ).

**TSA Measure for cognition and belief model:** To measure TSA according to the cognition and belief model, the method proposed by (Nonose et al., 2010) is used. Individual responses to the questions about their own cognition, beliefs and their team members' beliefs are compared as shown in Figure 6.15 above. When the cognition matches the belief of a team member, 1 point is awarded to the individual for that question. The percentage of the correct matches is calculated to develop the TSA measure of each individual.

The result of TSA measurement using this cognition and belief model is shown in Figure 6.23. The TSA performance percentage of the individuals using SAVER is 100%, which means that they were able to correctly state their team members' cognition for all the questions. A paired sample T-test shows that there is a significant difference ( $t = 3.47$ ,  $p\text{-value} = 0.003$ ) in the score for not using SAVER ( $M=84.4$ ,  $S.D=17.8$ ) and the score for using SAVER ( $M=100.0$ ,  $S.D=0.0$ ).

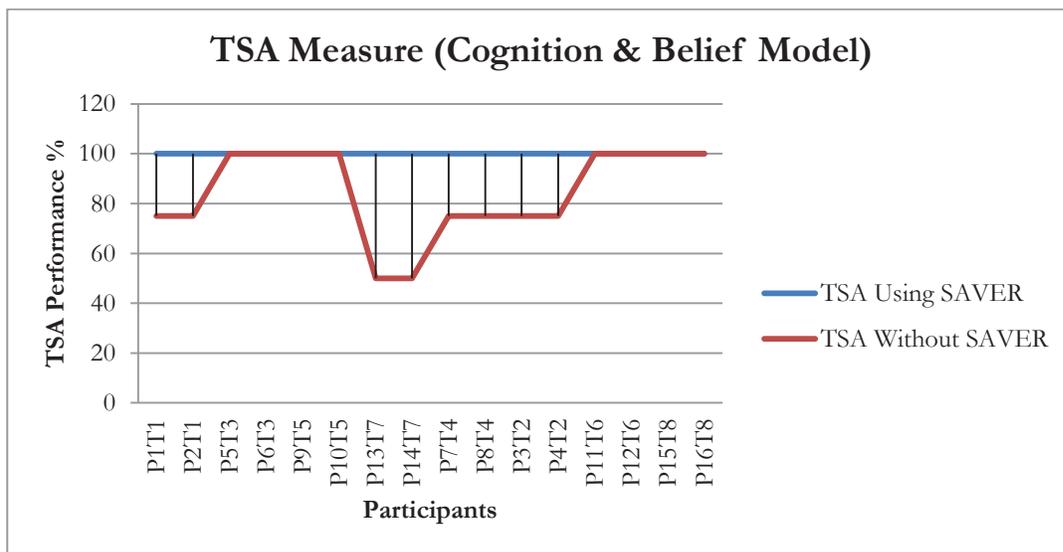
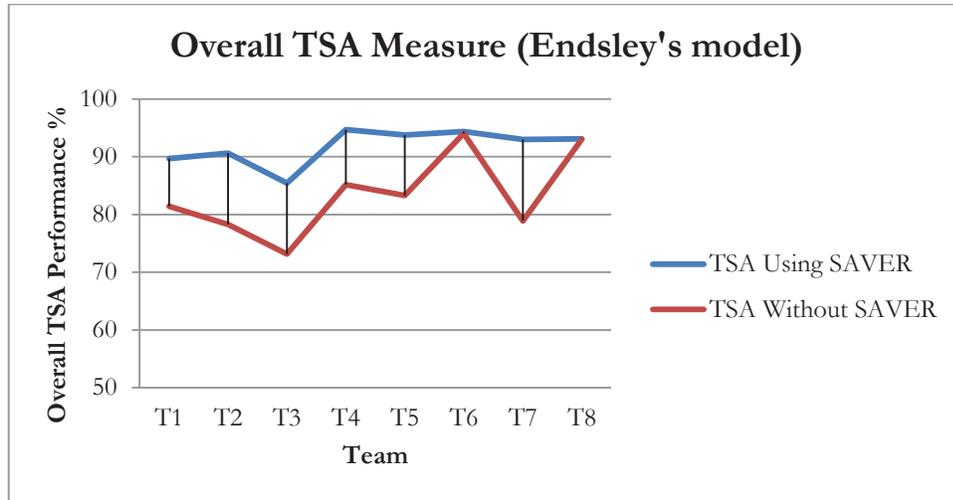


Figure 6.23 TSA score according to Shu and Furuta (2005) model

**TSA Measure (Endsley's Model):** To measure TSA according to Endsley's model, team members' individual SA performance score is averaged. The result of TSA

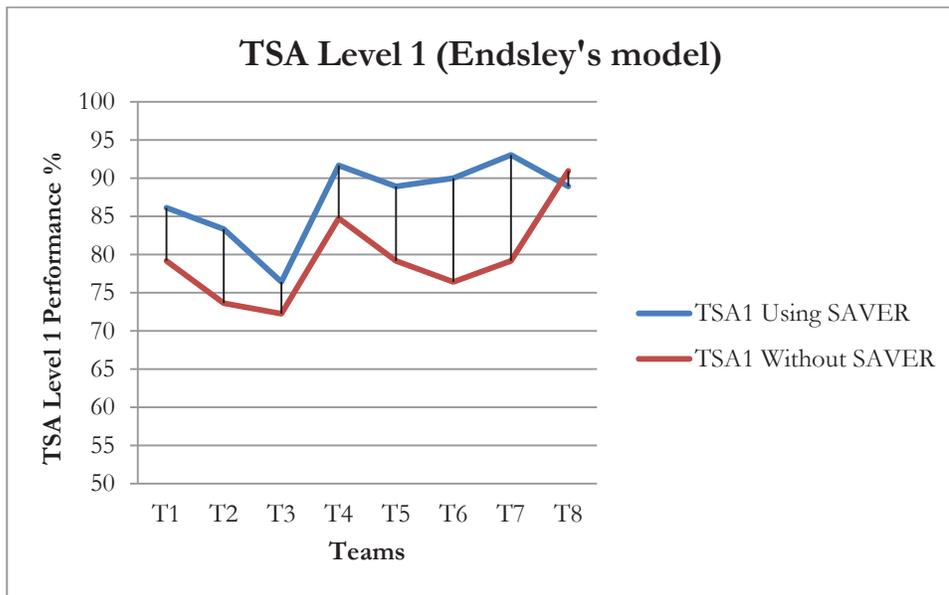
measurements according to Endsley's model is shown in Figure 6.24. The result shows that the TSA performance of the teams using SAVER is much better than those not using SAVER. A paired sample T-test shows a significant difference ( $t = 4.42$ ,  $p\text{-value} = 0.003$ ) in the score of non-SAVER users ( $M=83.4$ ,  $S.D=7.2$ ) and the score of SAVER users ( $M=91.8$ ,  $S.D=3.1$ ).



**Figure 6.24 TSA score with and without SAVER**

The above results are further broken down into the three levels of TSA to analyse the TSA performance of teams at each level. Responses to questions targeted at each level of TSA are isolated according to the TSA level and the percentage score of the team members is averaged to provide the team's TSA at the requisite TSA level.

Figure 6.25 presents level 1 TSA for the teams.

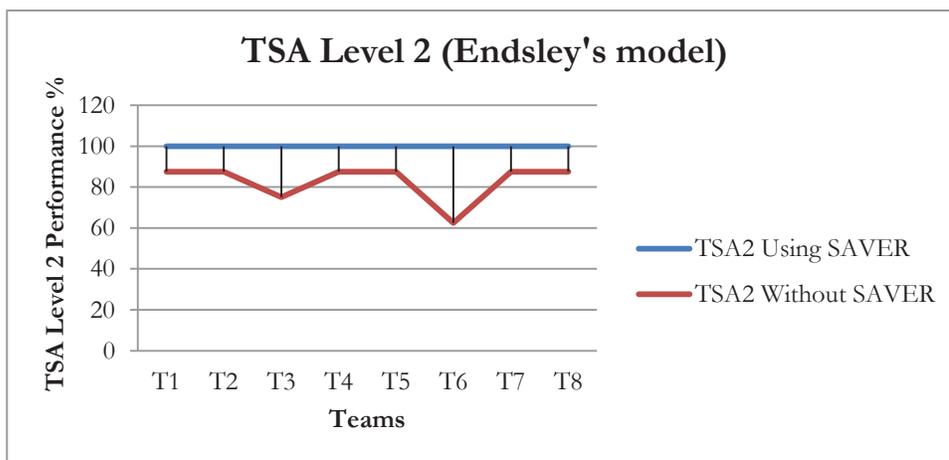


**Figure 6.25 TSA Level 1 measures with and without SAVER**

The result of measuring Level 1 SSA using and without using SAVER shows an enhanced performance by the participants using SAVER during the experiment. A paired sample T-test shows a significant difference ( $t = 4.26$ ,  $p\text{-value} = 0.004$ ) in the score of the participants using SAVER ( $M=87.3$ ,  $S.D=5.3$ ) and the score while not using SAVER ( $M=79.4$ ,  $S.D=6.0$ ).

Figure 6.26 presents Level 2 TSA for the teams.

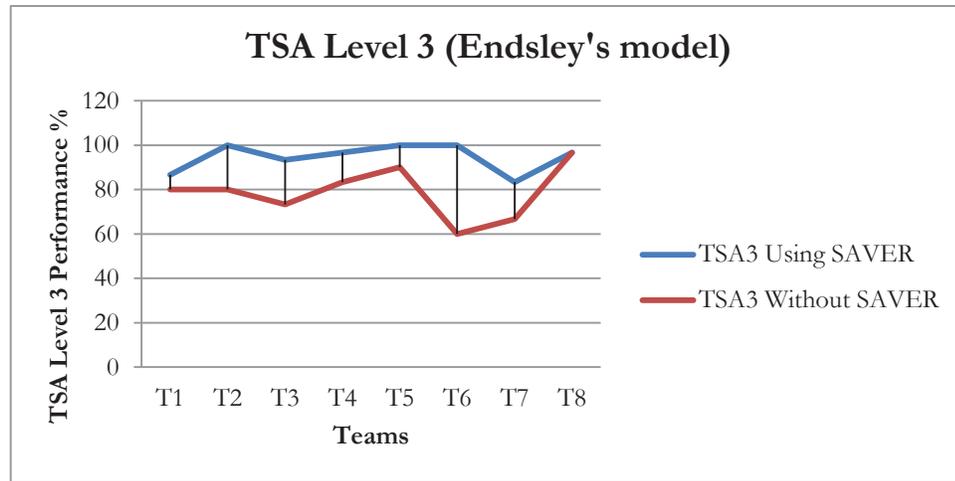
Figure 6.26 shows the results of measuring Level 2 TSA with and without SAVER. The results show that the TSA of the SAVER users is 100%. A paired sample T-test shows a



**Figure 6.26 TSA Level 2 measures with and without SAVER**

significant difference ( $t = 5.22$ ,  $p\text{-value} = 0.001$ ) in the score of the participants not using SAVER ( $M = 82.8$ ,  $S.D = 9.3$ ) and the score of the participants using SAVER ( $M=100.0$ ,  $S.D=0.0$ ).

Figure 6.27 below presents level 3 TSA for the teams.



**Figure 6.27 TSA Level 3 measures with and without SAVER**

Figure 6.27 shows the TSA Level 3 score of participants with and without SAVER. The results again confirm that SAVER improves TSA at Level 3. A paired sample T-test shows a significant difference ( $t = 3.75$ ,  $p\text{-value} = 0.007$ ) is found in the score of the participants not using SAVER ( $M=78.7$ ,  $S.D=11.9$ ) and the score of the participants using SAVER ( $M=94.6$ ,  $S.D=6.4$ ).

The results above show that TSA on all three levels was improved by using SAVER during the experiments. Since TSA score was based on the individual SA scores and significant improvement in these scores have been discussed earlier in Chapter 5, noteworthy improvements in TSA are expected and confirmed.

## 6.6 Summary and Conclusions

In mass evacuation operations, more than one organization is involved in decision making and task completion and the huge involvement of many individuals from numerous organisations highlights the importance of co-ordinated efforts. Hence, in addition to the individual SA, the team SA and shared SA are also critical. This chapter examines the requirement of team co-ordination to develop a necessary level of shared SA and TSA.

Developing a common understanding of a prevailing situation is the first step in making a decision to normalise the situation. Getting a consensus is time consuming, especially when team members have varied roles with different backgrounds and diverse responsibilities. Moreover, large collaborative tasks require the division of work in teams, where team members require support from others, mostly in the form of information. To support the team members effectively and efficiently, information required by the other team members can be shared proactively. However, since many organisations are involved in large operations, it is difficult for an individual to remember the details of everyone's requirements who are dependent on them.

In this chapter, an information system design based on proactive sharing of information using ontologies is proposed and evaluated. Information requirements and user context ontologies developed in Chapter 4 and Chapter 5 respectively are re-used and extended by adding the source and destination of the information flows. This enables the automatic routing of the right information requirements to the right people using an ontology reasoner (Fact ++).

It is proposed that providing an explicit assessment of the situation improves the common awareness among team members. Sharing the team member's understanding of the situation also improves their shared understanding. Moreover, automatic reminders about the team member's requirements improves SSA and also lifts the cognitive load of emergency managers since they do not have to remember every team member's information requirements.

The proposed design extends the prototype, SAVER, based on the above ideas. To evaluate this extension, the SSA and TSA of emergency managers are measured at all three levels. The results show that SAVER not only significantly improves the SSA at all three levels but also improves the overall SSA of teams. It appears that the SAVER's suggestions about the information requirements of team members to develop and maintain SA improves the SSA of the teams. Reminding them about their own requirements and their team members, helps them to keep the team member's requirements in sight. Moreover, this facility reduces the cognitive load needed to remember team member requirements since SAVER keeps track of these and issues reminders when required.

TSA has been measured according to its three prevalent definitions (models). Firstly, TSA is measured according to Endsley's model (Endsley & Jones, 2001), which describes TSA as the degree to which every team member possesses the required SA for his/her responsibilities. For this model, the individual SA of team members is combined to generate a TSA measure. Secondly, TSA is measured as a common or shared understanding of the situation (Salas et al., 1995), individual answers from the individual SA measure are compared to see the matching answers. Lastly, TSA is measured according to Shu and Furuta (2005) model of cognition and belief. For all three prevalent models of TSA, performance of the SAVER users was expressively better than the non-SAVER users. SAVER improved TSA by following a few simple steps like sharing the SA of one team member with the others, or by providing the same explicit assessment of the situation to all members. These steps not only helped team members to develop a common understanding of a situation, but also helped to support them to develop their beliefs about the team members' SA.

In our experimental environment teams consisted of only two members and the constrained design, implementation and evaluation of SAVER must be seen as a proof-of-concept study. In real emergencies, team sizes would be much bigger and managers' roles and situations more complex. Scaling SAVER could produce a system with the capability of improving SSA and TSA resulting in highly effective and efficient team decision making and collaborative task completion. This functionality is at the core of mass evacuation operations and overall emergency management and the SAVER concept has much to offer as a building block of change.

# Chapter 7

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## DISCUSSION

### 7.1 Introduction

The requirements of emergency managers to act effectively and efficiently in emergency situations are highly dynamic and complex. Both physical and cognitive factors affect their decisions and activities. This chapter first identifies situation awareness (SA), shared SA (SSA) and team SA (TSA) as the factors that affect individual and team decision making and task performance in emergency situations, and proposes changes to their formal definitions to clarify their meanings. The main part of the discussion then focuses on an interpretation of the results of the SAVER design, implementation and evaluation studies to improve these factors as set out in previous chapters. The chapter then discusses the relationships between the various models of TSA and describes the implementation requirements of an operational SAVER system. The chapter concludes with a summary of the whole research.

### 7.2 Formalising SA, SSA and TSA Definitions

As mentioned earlier (Chapter 2), there are multiple definitions of SA, SSA and TSA (Uhlarik & Comerford, 2002), not all of which are consistent, and a challenging task during this research was to understand and select the right ones since these concepts are central to the study. The following discussion, whilst somewhat arcane, endeavours to unravel and clarify some of the definitions and demonstrate the rationale behind choices. The presentation repeats some of the material presented in the literature review (Chapter 2), in order to develop a consistent and coherent approach to SA.

Situation awareness is the most fundamental concept since it underpins the other two (SSA and TSA), and accordingly it has been the subject of the highest level of controversy. Leaving aside vague, everyday definitions that lack scientific rigour and domain specific meanings that defy generalisation, a common assumption in several definitions is that a certain level of SA may be enough to carry out a task successfully (assuming adequate execution) without acknowledging that a higher level of SA can lead to improved performance. Similarly, there is insufficient recognition in several

definitions that SA is a dynamic factor, valid for a particular time and that it may need updating when the situation changes. These aspects are especially important in emergency situations.

The most widely used definition of SA by Endsley (1995a), 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 near future” (Endsley, 1988a).*

has also faced criticism. An interesting debate concerns whether SA is a process or a product. Endsley’s definition categorises SA as a product that is the result of a process of “situation assessment”. However, others like (Fracker, 1991; Uhlarik & Comerford, 2002) call it a process to obtain the required knowledge of a situation. They argue that the perception, comprehension and projection elements of SA definition can all be considered as processes.

Since SA is a measurable outcome characterised by absolute (often numerical, e.g. an aircraft’s altitude) or relative quantities, Endsley’s definition seems the more logical. Another issue (Uhlarik & Comerford, 2002) concerns whether measures of SA are objective or subjective quantities. Endsley believes they are objective since the measured values can be compared with true values whereas Fracker (1991) prefers a subjective interpretation because data is acquired via self-reports rather than direct observation. Although this is perhaps a minor distinction, it has led Fracker to categorise SA data as retrospective (obtained on completion of a task), concurrent (on-line acquisition) and frozen (collected at a pause in the task). The freeze technique resolves the objective/subjective debate to some extent because, as Endsley argues, pausing a process allows participants to focus on task related questions and provide considered answers without the distraction of time related problems and mental overload issues.

These arguments, and its simplicity, recommend Endsley’s model of SA as a theoretical framework and the freeze method of measurement for the current research.

However, an even more important reason for accepting her definition is the valuable division of SA into three hierarchical levels, which allows the construct to be measured easily and effectively. Moreover, this division allows the abstraction of SA requirements and the development of design guidelines and training strategies to support the acquisition of SA at different levels. In addition, Endsley’s model attempts to outline the

various factors that affect the development and maintenance of SA and includes a comprehensive set of individual, task and system factors (Salmon et al., 2009). Finally, Endsley (1988b; 1990; 2000) provides a proven method, Situation Awareness Global Assessment Technique (SAGAT), which measures SA at different levels in terms of the number of correct answers to questions asked about the situation. Therefore, rather than a product or process, SA can be regarded as a state of knowledge about the situation, which is measured as a “degree” or “extent”; the higher the degree the better the SA. We therefore propose a slight modification to the Endsley’s SA definition, which may silence some of the debates about the concept:

*“The degree to which an individual has 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”.*

The rather odd sounding “volume and space” component in the definition could also be replaced to generalise the change aspect as:

*“The degree to which an individual has the perception of the elements in the environment at a particular instant, the comprehension and the projection of their status in the near future”*

One more reason for considering SA as a degree (extent) is the connection with Endsley’s definitions of SSA and TSA. Since SSA and TSA are similar concepts as SA and are based on it, they are also defined in terms of degree. For example, the most widely used and accepted definition of SSA is

*“The degree to which team members have the same SA on shared SA requirements” (Endsley & Jones, 2001).*

However, this definition assumes that the shared SA is always correct whereas in practice it could be based on wrong or incomplete SA requirements. In the current work, our evaluation of SAVER avoids this ambiguity by measuring not only shared awareness on SA requirements but also by checking the requirements for accuracy. In addition, the definition does not indicate the required degree of the shared awareness between participants, which needs only to extend to those requirements necessary for successful task completion. Requirements that are irrelevant to a shared awareness of a particular task will not contribute to the SSA for that task so that a complete (or same) shared awareness between co-operating team members is not essential. We can handle this condition by making a small change to the definition:

*“The degree to which every team member has the awareness of his/her relevant team member’s requirements of perception, comprehension and projection of the situation”.*

Another important concept related to the collaborative tasks is team SA (TSA). Like SA, and SSA, TSA has also faced conflicting definitions (Endsley and Jones, 2001; Shu & Furuta, 2005; Salas et al., 1995). Endsley and Jones defined TSA as:

*The degree to which every team member possesses the situation awareness required for his or her responsibilities” (Endsley, 1995b; Endsley & Jones, 2001).*

According to this definition, TSA is the accumulated SA of all team members, a statement that disguises the interactions between team members that update each other’s SA and influence their task performance by supporting them and dividing the workload. These important team factors should be evident within the definition.

Salas et al. (1995) gave a totally different perspective to TSA as:

*The shared understanding of the situation among team members at one point in time”.*

focusing on the degree to which team consensus about the situation and its future evolution are required for decision making and collaborative task execution. Without consensus a team cannot act co-operatively to normalise a current or forecast situation. As with SSA, the definition of TSA by Salas et al. (1995) does not say anything about the correctness of the shared understanding of the situation. However, in our evaluation of SAVER while measuring TSA, we considered only those shared answers of team members that were correct in the first place.

Close to the ideas of Salas et al. (1995) on TSA is the cognition and belief model by Shu and Furuta (2005). According to these workers, TSA is defined as

*“Two or more individuals who share the common environment, up to the moment understanding of the situation of the environment and other person’s interaction with the co-operative task.” (Shu & Furuta, 2005).*

In addition to “sharing the understanding of the situation”, this definition adds the team member’s interaction with the co-operative tasks missing from the Endsley version. This is useful for collaboration since to provide timely input and support to a team member, an individual should know when that team person is taking action.

Moreover, Shu and Furuta also introduced the concepts of mutual beliefs which describe what each individual believes about his/her team member's understanding of the situation, and beliefs about what that team member believes about the individual's understanding. Having a correct view of a team member's understanding of the situation is very useful since, in this way, a team member's SA can be updated if there is some problem in the understanding of that team member. Therefore, these concepts of cognition and belief are critical for the team's collaborative tasks and team decision making. Although for the evaluation of SAVER we have measured TSA according to all the models discussed above, we consider the cognition and belief model of Shu and Furuta (2005) as the most realistic, since it encompasses the TSA definition by Salas et al. (1995). However, the belief about a team member's understanding should be part of the definition and we propose that TSA is:

*“The degree to which related team members have the shared perception, comprehension and projection of the situation and correct belief about a relevant team member's perception, comprehension and projection of the situation”*

In this definition the term “related team members” limits the sharing requirement to only those team members who need to have a similar understanding of the situation since some may not require to understand the situation at all, e.g. if it is not relevant for their task or job role. Moreover, the “relevant team member” in the second half of the definition is the person whose belief needs to be known by the individual to ensure effective collaboration.

The new definitions proposed above attempt to clarify the relationships between the definitions of SA, SSA and TSA. More work is needed to produce a fully integrated and consistent perspective but the suggested improvements help the design of experiments to measure the different forms of situation awareness. Viewing SA as a state of knowledge about the situation by an individual or a team also underlines the utility of computer based systems to improve awareness.

Moreover, to support SSA and TSA from every aspect, SSA and TSA are divided into three levels like SA (Endsley, 1995b). The division of SSA and TSA into levels will help in identifying the detailed information requirements of each level. See Table 7.1 for the division of SSA and TSA into three levels. This division has not been reported previously and it would be interesting to explore it further.

**Table 7.1 Levels of SSA and TSA**

Concept	Level	Definition
SSA	1	The degree to which every team member has the awareness of his/her relevant team member's requirements of perception of the situation
SSA	2	The degree to which every team member has the awareness of his/her relevant team member's requirements of comprehension of the situation
SSA	3	The degree to which every team member has the awareness of his/her relevant team member's requirements of projection of the situation
TSA	1	Degree to which relevant team members possess common/shared knowledge of the relevant elements (perception) to the prevailing situation and correct beliefs about the relevant team member's perception
TSA	2	Degree to which relevant team members possess common/shared knowledge on the understanding (comprehension) of the situation elements and correct beliefs about the relevant team member's comprehension
TSA	3	Degree to which relevant team members possess common/shared knowledge on the projection of the situation elements and correct beliefs about the relevant team member's projection

### **7.3 Information Requirements for SAVER Design**

The objective of this study is to develop a computer based system to support the SA of individuals and teams, i.e. SA, SSA and TSA. The systems design is therefore based on the information required for developing and maintaining the different forms of awareness. Obtaining these information requirements is complex since they include not only the factual information needed for the various roles and associated tasks but also information on the cognitive processes that lead to the realisation of situation awareness.

This study has used a cognitive task analysis technique named Extended Goal Directed Information Analysis (EGDIA), which has proved very useful in capturing both physical and cognitive information requirements (section 4.4.1.3, Chapter 4). The scope of the study was limited by the number of experts (emergency managers) and their availability for the simulation experiments and consequently, the requirements analysis was restricted to the roles of these participants. However, 13 out of the 16 New Zealand Civil Defence Emergency Management Groups participated and this number was sufficient to cover the majority of the important roles and validate their requirements.

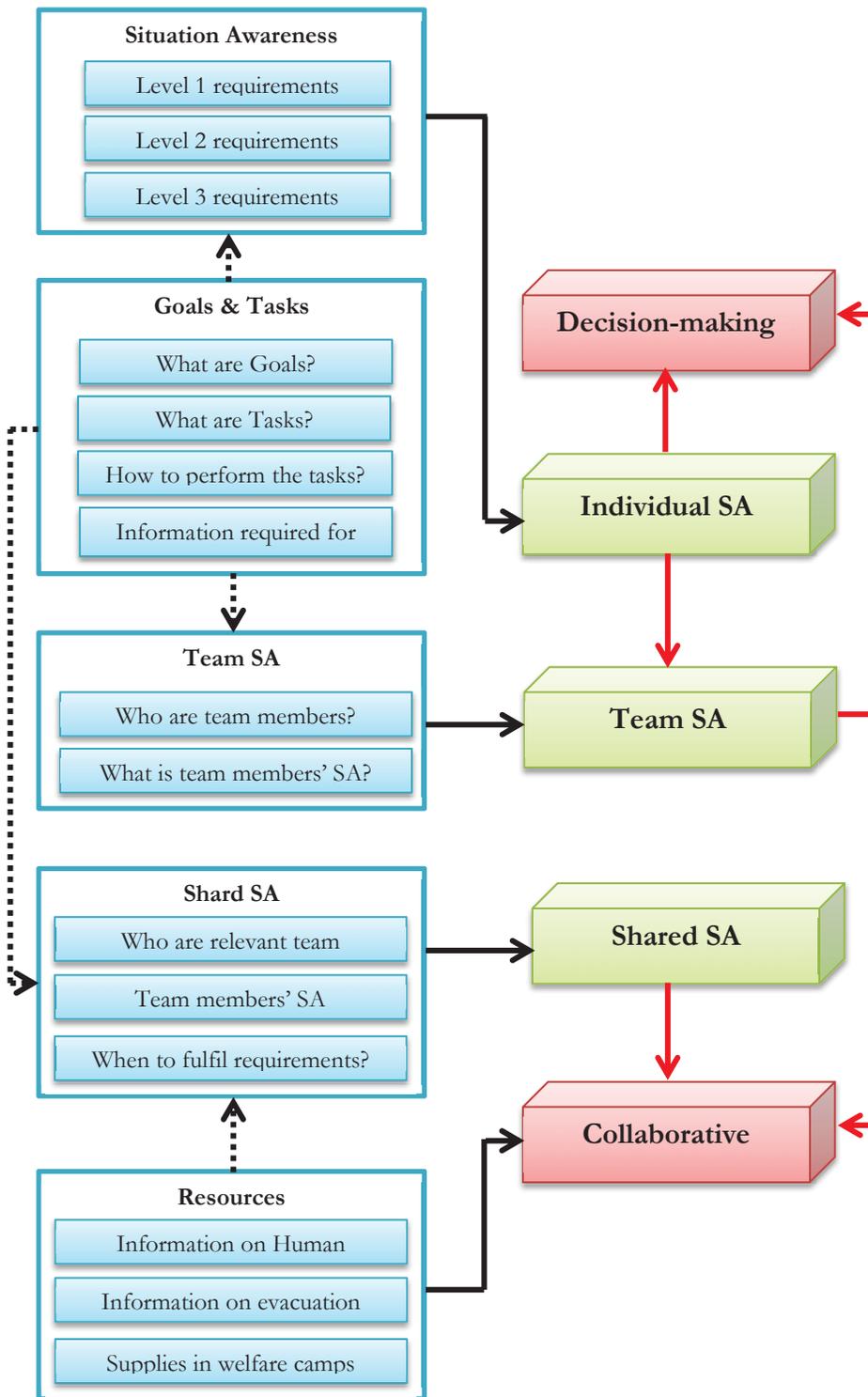
As described in earlier chapters, SAVER was evaluated by a tsunami simulation so that the information requirements covered the roles for mass evacuation following such an event. These requirements can be adapted and extended for other types of emergency, e.g. flood, hurricane, volcanic eruption and a production version of SAVER could use EGDIA to develop and validate comprehensive sets of information requirements for each situation.

In an emergency, responders will invoke different mental models depending on their experience and they can also use different data sets to reach the same conclusion. This study therefore, only attempts to gather the standard or generic information requirements sufficient to develop and maintain the levels of SA needed for decision-making and task performance. However, the information requirements were captured via questionnaires from managers throughout New Zealand and the level of consensus across the responses strongly suggests that the generic set was detailed enough to achieve these goals. Again, in a production environment, the SAVER design could update data sets as dictated by improvements in the situation awareness.

Figure 7.1 (next page) summarises the relationship between the various levels and types of information requirements used in this research and their involvement with decision making and task performance.

## **7.4 Ontology-based SA, SSA and TSA**

Several researchers (Mathues et al., 2003; McGuinness et al., 2003; Horney et al., 2003; Boury-Brisset, 2003) have proposed ontologies for the representation of situation awareness. These studies use mainly general descriptions to describe classes and their properties and demonstrate how a situation can be expressed in computer processable terms. The present study takes the approach well beyond this purely modelling, descriptive stage and maps every level of SA to ontologies with the goal of improving situation awareness at each level. Coupling ontologies with a reasoning capability also leads to projections (Level 3 SA) that generate additional knowledge about the concepts not explicitly described in the relationships.



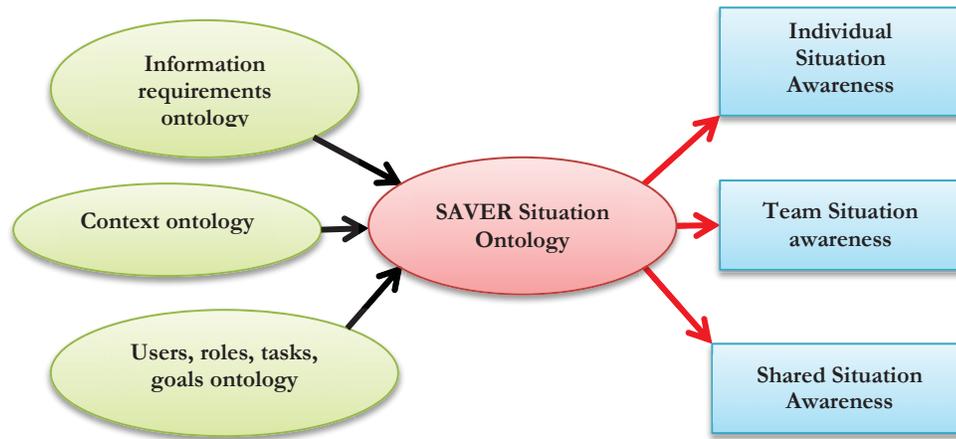
**Figure 7.1 Various types and flows of information requirements**

As explained in Chapter 4 the information requirements of emergency managers are represented in Web Ontology Language, OWL, which is machine readable. In this research, OWL reasoning capabilities have proven useful for the simulated scenario experiments and it is evident that the expressive power of OWL is sufficient to model

even very complex situations. This allows the development of an architecture that provides a detailed approach and procedures, not just for modelling situations, but for automatic situation assessment, which is a principal objective of the study. Another advantage arises from the re-usability of modelled information requirements and the user's context information as seen later in the study when ontologies initially developed to support individual SA are re-used for supporting SSA and TSA. Moreover, after the dynamic modification of relationships or addition of concepts, the ontology reasoner (e.g. Fact Plus Plus) can check for errors and contradictions so that the modification can be automatically validated. Last, but not least, ontologies can be used to directly represent the reality of a situation without introducing abstractions like database tables, dictionaries or documents.

However, all these advantages come at some cost. Developing ontologies is difficult and time consuming while re-usability of the existing ontologies has issues related to the level of abstraction and the intent of their creation. Making them re-usable takes a considerable amount of time and effort and it can be more straightforward to develop a new ontology from scratch. Nevertheless, substantial research is under way to improve the re-usability of ontologies. In addition, current ontology reasoners (Racer, Pellet, Fact Plus Plus, Hermit, etc.) still have some performance issues when classifying and reasoning for complex and large OWL ontologies (Dentler et al., 2011; Huang et al., 2008). Though the rapid increase in computing power is gradually overcoming this problem, it is still an issue now and in the foreseeable future.

On a positive note, the reasoning and scalability capabilities of OWL are improving due to the addition of new features such as property chains, richer data types and data ranges, qualified cardinality restrictions and asymmetric, reflexive, and disjoint properties (Bassiliades, 2012). Mapping and integrating OWL and database technologies can also improve performance and extract more information from the data, (Zhuge et al., 2008). The use of ontologies in various parts of this project is summarized in Figure 7.2.



**Figure 7.2 Various ontologies in SAVER**

### 7.5 Improving SA using SAVER

As the evaluation results show, the use of SAVER improves SA at all three levels. Few studies have measured the SA of participants in “before and after” environments designed to improve situation awareness as this study does. Most of the studies have measured SA to see the effect of some specific factor, e.g. experience level, communication or training etc. (Hauland, 2008; Saner et al., 2009; Bolstad and Endsley, 2003; Bolstad, Cuevas, and Costello, 2005). Moreover, to our knowledge, there is no study in the emergency decision making domain that attempts to improve SA using computer based systems and then evaluates the design by measuring the SA of users. Direct comparison with the SA measurement results of other studies is therefore not possible.

As noted, SAVER uses SA-oriented design principles proposed by Endsley et al. (2003) (See also Bolstad et al., 2006) in which relevant Level 2 and Level 3 SA information is provided to emergency managers in a format that describes the significance and implication for current and future situations so that they can internalise it and process it quickly. Only contextualised and personalised information is delivered depending upon the managers’ roles in the current emergency phase and the tasks they are performing. In contrast, when emergency managers receive raw data about the situation, they need to select the relevant components and then process them, which is a time consuming task under dynamic and stressful conditions. Use of SAVER therefore saves time and reduces distracting workload, valuable benefits during a crisis response. The time evaluation in the current study only reflects the time for retrieving SA information whereas it would be interesting to see the time taken by each user to develop their

situation awareness after receiving the information. Since SA is a cognitive attribute, capturing the time taken to develop SA is quite involved and it will require careful experimental design.

Since emergency managers' perceptions affect their comprehension and the resulting projection of the situation, mistakes or errors in Level 1 SA can result in flawed SA at Levels 2 and 3. However, though SAVER supports SA on all three levels, its use does not require its users to keep up with the SA on every level. For example, if there are mistakes in perceiving the situation elements (Level 1 SA), SAVER can directly update a user's SA on Level 2 via the direct interpretation of situation elements. Similarly, even if the understanding of the situation (Level 2 SA) is defective, SAVER will update Level 3 SA directly reducing and controlling mistakes in decision making and task performance.

Analysis of the results show a substantial difference in the SA performance of the novice and experienced emergency managers when the participants were not using SAVER (section 5.5.2.4). In this circumstance, the SA performance of the experienced emergency managers was significantly better than the novice ones. This agrees with the explanation by Endsley, (1995a) and others (Klein, 1999) that the SA of individuals depends on their experience level. However, when participants were using SAVER, there was no statistically significant difference in the SA of both groups based on their experience levels. This is an important conclusion since it reduces the dependence on experienced managers who may not be readily available during an emergency. With the effective use of such systems, even novice emergency managers can perform as well as experienced emergency managers. SAVER also improves the SA of the experienced emergency managers, thus, reducing the chances of errors. These results also highlight the improvement that SAVER brought to the SA performance of the participants – see Table 7.2 which shows the percentage of correct answers to questions at the freeze points of simulations with and without SAVER (section 5.5.2.4).

**Table 7.2 Comparison of experienced and novice emergency managers' performance with and without SAVER**

Manager Type	% Correctly Answered Questions	
	Without SAVER	With SAVER
Novice managers	75.2	89.9
Experienced Managers	84.0	93.8

Analysis of the time for answering the SA questions also illustrates that SAVER users took significantly less time than the non-SAVER users. Hence, the efficiency of the SAVER users was much better in retrieving SA information on all three SA levels. Saving time can significantly improve decision making and task performance.

The human computer interface is a crucial component of emergency systems design, which should be intuitive and simple enough to make the system usable. A complex interface would keep the user occupied in figuring out how to perform the task instead of concentrating on the solution. The simplicity of presentation and the focus on SA requirements contributed directly to the positive assessment of SAVER. Nevertheless, the user interfaces can be improved further by performing detailed requirements analysis and involving emergency managers in the design of screens that support their individual and combined roles and tasks.

Evaluation of SAVER by only 16 emergency managers was enough for a proof of concept but more experiments with more users are required to generalise the findings. The current study evaluates SAVER by measuring the SA of the emergency managers but the quality of the decisions made or tasks performed could also be used as parameters for evaluation and perhaps reveal other important factors affecting SA. However, differentiating between 'good' and 'bad' performance is intrinsically subjective and difficult to formulate.

## **7.6 Improving SSA using SAVER**

Co-ordination and information sharing are central to the collaborative tasks of a team and SAVER proactively shares information requirements between team members,

making use of contextual information, the overall common goals, the shared tasks, and the resulting flow of the information to fulfil members' information requirements.

While designing the SSA module of SAVER, it was hypothesised that requesting users for the information requirements of their relevant team members would not only make them aware of these member's requirements but also lead to the timely fulfilment of their information needs. This hypothesis was tested by measuring the user's SSA. Significant improvements were found in the SSA of SAVER users compared with non-SAVER users, confirming the successful design of the SSA module.

The teams for these tests were randomly selected so that members were unaware of each other's background, experience level and working style (tacit knowledge) (Paton & Jackson, 2002) etc. However, they still managed to perform very well during the collaborative task, strongly suggesting that the proactive sharing of team members' information requirements can be very useful in such situations making it unnecessary for members to know about these requirements beforehand. In addition, they are not required to remember the requirements since SAVER can remind them. These advantages become increasingly important as the size or number of collaborating teams increases.

All the participants were aware of the Planning and Intelligence (P&I) function of Coordinated Incident Management Systems (CIMS) but not necessarily familiar with the preparation of a SitRep. Preparing the SitRep is the responsibility of specialised roles namely Situation Reporting and Planning and Intelligence Manager. Only half an hour of the introductory session was allocated to the participants describing their responsibilities and how to write the SitRep. Although no data about their previous knowledge of the task was gathered, their SSA performance was quite satisfactory (see section 6.5.2.2) while using SAVER (M=78.5). These results can be credited to SAVER, which was reminding the participants about their team member's relevant information requirements as well as compensating for the participant's lack of specialist knowledge.

Though the SSA of non-SAVER users is significantly (statistically) lower than the performance of SAVER users, it is also reasonably good (M=67.3). This performance level is almost certainly due to the ease of the task since there were not many shared information requirements or flows in the simulations. It would be interesting to evaluate SSA in more complex situations where many shared and uncommon information

requirements are involved, and to obtain a more detailed picture of SSA by collecting data about team members' knowledge of the roles, tasks of others using and without using SAVER. Furthermore, the current study uses teams of only two members (to make eight teams); experiments with larger teams will be useful to produce results that are more generalizable.

## **7.7 Improving TSA using SAVER**

When teams are involved in decision making, consensus is required to reach a decision. Agreement on an understanding of the situation is the first step, discussing the options or actions to normalise it comes next. The larger the team, the more time it takes to get an agreement. This is because different team members have diverse backgrounds, experience, intelligence level etc., and they process the same information differently according to their different roles and attendant sub-goals. SAVER provides the explicit situation analysis along with the logical arguments (rules it uses to reach conclusion) to provide a common understanding of the situation.

In this study, the hypothesis that providing the explicit situation assessment improves the common situation understanding is tested by measuring the TSA of participants. This is done by measuring the individual SA of the participants with and without SAVER and checking commonality across the team members. The results show that the TSA score of SAVER users is significantly better than for the non-SAVER users. This result is, of course, intuitively expected but the statistical evidence shows uncontrovertibly that SAVER overcomes the 'silo effect' of independent assessment and awareness and helps team members to make consensus decisions. Because SAVER is a prototype working with comparatively simple scenarios, the conclusion should be regarded as proof-of-concept but it implies that the result will be scalable to large production systems and more complex situations, and this can be confirmed by more studies.

The current study also evaluated SAVER by measuring team SA according to the TSA definition advanced by Endsley and Jones (2001). For this purpose, team member individual SA scores were averaged to get the team SA score. The TSA score calculated in this way for the teams using SAVER was significantly better than for the non-SAVER user teams.

The TSA tests show the strong dependency between TSA and individual SA and the design of systems supporting TSA should not only concentrate on team communication and co-ordination but also on the SA of individuals. Moreover, instead of concentrating on one of these TSA models, the system design should consider all three as they complement each other and the resulting team performance. If one of them is missing, TSA will be flawed. Hence, instead of calling all of them TSA, which creates confusion, they can be combined to represent team SA as defined in the previous section.

Though the tacit knowledge and other team factors like communication between the team members, modes of communication, decentralisation of the team etc., are critical in team collaboration (Paton et al., 1999; Paton & Jackson, 2002; Smallman & Weir, 1999), they are not considered in the current study since their impact on the team performance is already studied. Moreover, tacit knowledge is acquired by getting team members to work together. SAVER's objective is to minimise this dependability. This will allow the more versatile and dynamic team creation. By sharing a team member's awareness directly, team members are not required to know each other to develop common understanding or beliefs. However, this hypothesis needs to be tested.

### **7.8 Relationship Between Individual SA and Various Models of TSA**

From the results discussed above, it can be seen that the common awareness of a situation (Salas et al., 1995) has some role to play in the cognition and belief model (Shu & Furuta, 2005) since TSA, according to the cognition and belief model, is high for those teams whose common SA (TSA) is high. Participants believed that their team members were choosing the same options as they were. Similarly, teams having high TSA according to the Endsley's model, have also high common SA. This effect was high when teams were using SAVER since they knew they were getting the same situation assessment. While using SAVER, the TSA score of participants is 100% due to the correlation between cognition, belief and common SA and cannot be compared without using SAVER. However, to confirm these relations, results of all the individuals (with and without SAVER) are combined and are checked for correlations as shown in Table 7.3.

**Table 7.3 Correlations between TSA as combined SA (Endsley & Jones, 2001), TSA as common SA (Salas et al., 1995), and TSA as cognition and belief model (Shu & Furuta, 2005)**

		TSA as Belief & Belief	TSA as Common SA	TSA (Endsley's model)	Individual SA
<b>TSA as Belief &amp; Belief</b>	<b>Pearson Correlation</b>	1	.84	.57	.32
	<b>Sig.</b>		p < 0.001	.001	.077
<b>TSA as Common SA</b>	<b>Pearson Correlation</b>	.84	1	.73	.54
	<b>Sig.</b>	p < 0.001		p < 0.001	.001
<b>TSA (Endsley's model)</b>	<b>Pearson Correlation</b>	.57	.73	1	.56
	<b>Sig.</b>	.001	p < 0.001		.001
<b>Individual SA</b>	<b>Pearson Correlation</b>	.32	.54	.56	1
	<b>Sig.</b>	.077	.001	.001	

Pearson correlation tests show that all the results in Table 7.3 are significant. Individual SA is highly correlated with Endsley's model of TSA since this form of TSA is simply the aggregation of a team member's individual SA. Similarly, the common SA of team members depends on the correctness of its own (individual) SA. TSA (cognition and belief) also rests on its own correct cognition of the situation. When own cognition is correct, common correct cognition is high, leading to the high belief that other team members have also understood the situation in the same way. Moreover, common SA itself is also highly correlated with the TSA as a cognition and belief model. Therefore, the high level of common SA results in improved belief about the team member's SA. Hence, all these TSA models seem interrelated and also dependent on the individual SA.

Consequently, the design of systems supporting TSA should not only concentrate on the team communication and co-ordination but also on the individual SA since a major part of TSA depends on it. Moreover, instead of concentrating on one of these TSA

models, the system design should consider all three as they complement each other and improve the resulting team performance. If one of them is missing, TSA will be flawed.

## **7.9 Implementation Requirements of SAVER**

The functioning and usefulness of SAVER has been demonstrated by the prototype but a considerable amount of work is needed to make it useable in a real environment. This section provides an overview for the development and deployment of the operational SAVER. It covers four main areas namely: organisational requirements, architectural requirements, user interface requirements and testing requirements to develop and deploy operational SAVER. The following sections discuss these requirements over a very broad spectrum.

### **7.9.1 Organisational requirements**

An in depth requirements analysis is needed to develop and maintain situation awareness of individuals and teams in the organisation under focus. The process of requirements analysis should consider all the emergency management roles and their tasks depending upon the emergency scenarios. Moreover, multi-organisation co-ordination requires agreement between organisations and comprehensive policies for information sharing and support.

### **7.9.2 Architecture requirements**

The architecture of the SAVER system is discussed below in terms of various components. While the architectural specification is to some extent provisional and subject to revision based on the results of further research, it is included in the context of the current discussion as a means of indicating a proposed implementation strategy for ontology based information systems to increase the operational effectiveness of emergency managers in emergencies by improving their situation awareness. Figure 7.3 (over page) shows a possible architecture of the operational SAVER.

#### ***7.9.2.1 Knowledge repository***

The knowledge repository can consist of a LargeTripleStore<sup>1</sup> to provide an adequate storage mechanism for the knowledge infrastructure of the application. With SAVER,

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<sup>1</sup> <http://www.w3.org/wiki/LargeTripleStores>

the knowledge infrastructure contains both conceptual knowledge and instance knowledge. The conceptual knowledge is represented using the concepts and relationships between the concepts, whereas the instance knowledge is in the form of individuals or values and the relationships between values and objects.

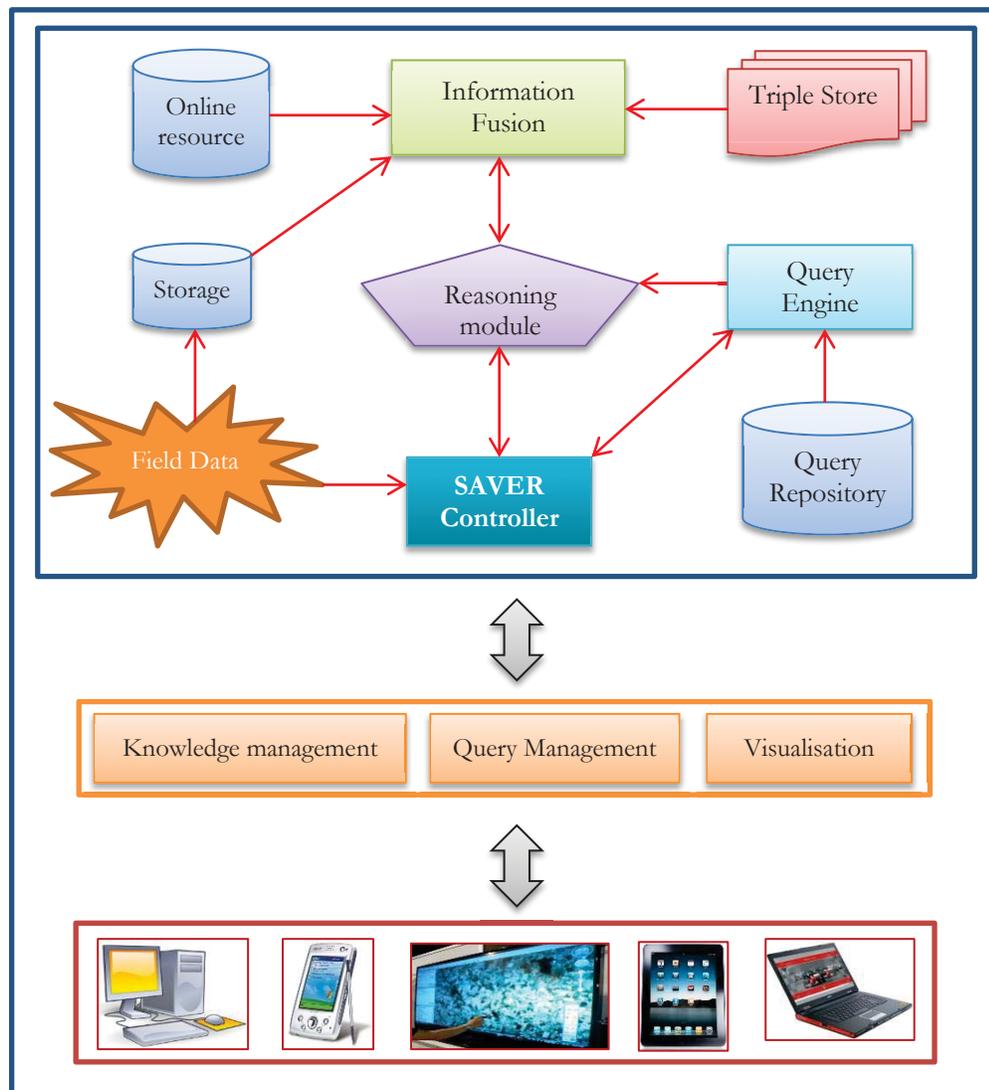


Figure 7.3 Architecture of operational SAVER

### 7.9.2.2 Knowledge management

The knowledge management module can make use of the tools to add, edit and append the ontologies in the system. These changes can come up due to the deficiencies in the existing models or may require updating in the dynamic emergency management

environment over the time. Third party tools like Protégé<sup>1</sup>, NeOn Toolkit<sup>2</sup>, or TopBraid Composer<sup>3</sup> etc. can be used for ontology engineering and management.

### ***7.9.2.3 Reasoning module***

The reasoning module exploits any reasoner for asserting the knowledge into the reasoning environment and retrieving the results of inference execution. Moreover, the reasoning module is also used to check the ontologies for any inconsistencies in the relationships or rules. The reasoner used in the current application is Fact Plus Plus, which is simple to work with and efficient for small size ontologies, however, various other reasoners, for example, Racer, Pellet, Hermit etc. can be evaluated to choose the best one (Dentler et al., 2011; Huang et al., 2008 ).

### ***7.9.2.4 Query repository***

The query library consists of a collection of predefined query templates that may be of generic use across multiple operational contexts. Currently, SAVER uses only a few queries saved in SAVER Controller (next section) for different situations and roles. However, a wide range of queries can be saved using ontological characterisation to facilitate more meaningful and rapid selection and retrieval. In addition to this, the results of most generic queries can also be saved for quick retrieval.

### ***7.9.2.5 SAVER controller***

The controller component of SAVER is like the central processing unit of a computer. It can be activated by the feeds from the sources to which it is subscribed or the user can manually activate it by adding an event into SAVER and asking it to monitor some specific information sources. SAVER controller can then make use of available information, the reasoner module and predefined queries to provide the situation assessment to the users. The SAVER controller works as a communication channel between the users and the SAVER system. All messages, notifications and event management is done by the controller.

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<sup>1</sup> <http://protege.stanford.edu/>

<sup>2</sup> [http://neon-toolkit.org/wiki/Main\\_Page](http://neon-toolkit.org/wiki/Main_Page)

<sup>3</sup> [http://www.topquadrant.com/products/TB\\_Composer.html](http://www.topquadrant.com/products/TB_Composer.html)

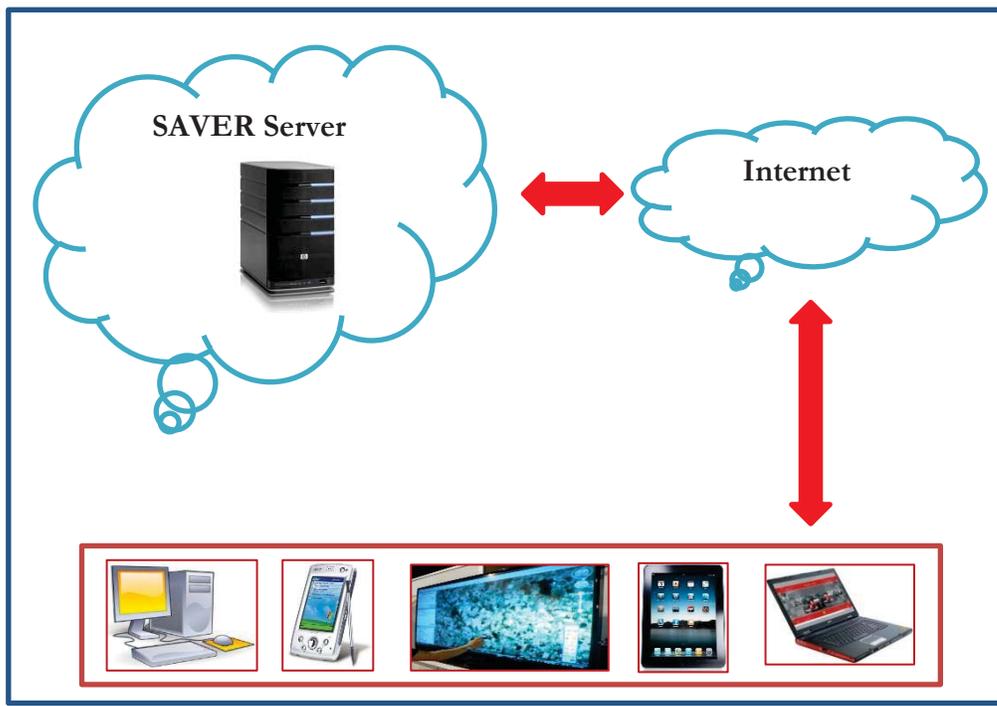
### ***7.9.2.6 Information fusion module***

An information fusion module can be used to integrate the information from diverse sources including information from within the SAVER system, for example from ontologies (TripleStore). The information is saved in the form of instances of ontologies and processed using a reasoning module to draw inferences according to the situation requirements.

### ***7.9.2.7 Computing and hosting requirements***

For a system like SAVER, quality and availability of service are very critical for the successful usage and trust of the emergency management sector. Both of these mandates come with huge cost and dedicated network resources. However, this cost can be reduced by using computing and storage facilities provided by cloud computing. In cloud computing there is a significant workload shift. Local computers no longer have to do all the heavy processing when it comes to running the huge applications (SAVER using large ontologies will require a huge amount of computing power). Moreover, using cloud computing, the hardware and software demands on the user's side also decrease (Strickland, 2008). The only thing the user's computer needs to be able to run is the cloud computing system's interface software, which can be as simple as a web browser.

SAVER is a web based application; therefore it can be divided into two sections - front end and back end. They connect through a network, usually the Internet. The front end is the side the computer users see; therefore, it can have very ordinary processing capability and only requires a web browser. The back end is the cloud section of the system, which is stored on the cloud in a secured environment and the cloud service providers assure its security. All the processing is done on the server side and hence the client side does not require the specialised hardware and software for running and storing large applications (see Figure 7.4). The reliability (and hopefully the security) of SAVER services will be assured by the cloud service providers. SAVER will become scalable in terms of storage space as well as the power it requires for processing the large and complex ontologies. Therefore, it can easily be extended to many other types of disaster contexts, organisations and thousands of users over the Internet.



**Figure 7.4 SAVER on cloud**

### **7.9.3 Graphical user interface (GUI) requirements**

The design and implementation of the GUI components need to take into account the specific visualisation requirements of different user groups. Moreover, the ergonomic configuration of such interfaces must consider the cognitive requirements of the end users. This is of significant importance for providing the interfaces to improve the situation awareness of individuals and teams. For this purpose detailed user interface requirements analysis is needed. This analysis should involve emergency managers in the design process and assure the availability of information in the format required by them.

#### ***7.9.3.1 SA, SSA and TSA oriented visualisation***

Interfaces should be designed by considering the factors that affect the situation awareness. For this purpose, as suggested in the design of the SAVER prototype, information should be arranged according to the goals and tasks of the roles. Moreover, the format of the information, i.e. pictorial, map, or text, should be used according to the requirements of the task. Adequate interfaces for chat and co-ordination should be provided along with the shared interface providing the overall up-to-date picture of the situation to improve the SSA and TSA of the team. Hence, all the design guidelines discussed in Chapter 5 and Chapter 6 should be used to improve SA, SSA and TSA of the individuals and teams by providing personalised interfaces for each role.

### ***7.9.3.2 Query visualisation***

The process of specifying appropriate queries is vital in the exploitation of the knowledge based systems. The queries central to the requirements of situation awareness need to be stored in the query repository as discussed above. Appropriate interfaces should be designed to allow building and execution of the customised queries. The interface should provide a way to build semantically enriched queries to take full advantage of an ontology based system. A very useful aspect in this regard can be the graphical query interface since, it does not require the users to know the knowledge architecture of the system. This area is still under research.

### ***7.9.3.3 Use of mobile devices and touch screens***

With the extensive improvement in the computing and graphical capabilities of mobile devices, they are now perfect candidates to keep the users up to date with the prevailing situation anywhere any time. SAVER is a web based application; therefore, it can be accessed on any device that is capable of running an Internet browser application. However, there is a need to develop adaptive interfaces so that a device can display information according to its capabilities. Moreover, large displays and multi-touch screens provide a new mode of visualisation and human computer interaction. Large screens can be used to provide a shared overall tactical picture of the prevailing situation improving team situation awareness. Similarly, touch screens can reduce the amount of learning required for information retrieval using textual queries or time consuming input by ordinary devices (e.g. keyboard, mouse, light pen) since maps and graphical components can be directly touched, dragged and dropped for input in a natural way. A combination of graphical query interfaces with the multi-touch screen would be an astonishing application of both these technologies.

### **7.9.4 Testing requirements**

SAVER has been evaluated for improving the situation awareness of individuals and teams. However, before using the operational SAVER in real events, it needs to be tested with real data for accuracy, especially with large data sets. This can be done by using SAVER in multi-organisational exercises or in actual events as a dummy system. A detailed functional testing will verify that it provides the functionality to perform all the required tasks. Non-functional testing will clarify other aspects like availability, scalability, performance, security, etc.

## 7.10 Summary

This research started with the requirement of an information system that can support the operations of managers in group emergency operation centres (GEOCs) during emergency situations such as mass evacuation. During the initial investigation of the literature and observations, it was noticed that emergency managers had mainly two types of responsibilities: 1) decision making, and 2) task performance. Decision making can be a requirement of a task or the task can be the result of the decision in the form of implementation. Both of these conditions require awareness of the situation. Since computer based systems are used in our everyday life as a solution to many problems, using them for improving SA seems entirely logical. Some questions linked to this idea were: how is situation awareness developed? What are its requirements? How to design a computer based system to support SA? Lastly, can a computer based system improve SA?

These questions started the quest for the requirements of SA. Information about the situation appears to be the main requirement and so the study moved to the identification of these requirements. Literature, as well as common sense, indicate that the greater the awareness of a situation, the better the decisions made. The performance of tasks similarly also depends upon the degree of situation awareness. However, it is the relevance (quality), not the volume of information provided to develop SA, that is the key factor so care is needed to select only the information that needs to be processed for the decision or task at hand, thereby balancing workload and completeness.

In emergency situations, acquiring situation awareness is more challenging than in normal situations due to stress levels, limited time, changing situation, etc. In this study, the information requirements are acquired by a Cognitive Task Analysis (CTA) based technique called Extended Goal Directed Information Analysis (EGDIA). This technique has the ability to capture the information requirements of cognitive processes along with the physical tasks. EGDIA is quite useful and comprehensive information requirements are gathered for various roles of GEOCs.

This research focuses on emergency situations involving a mass evacuation following a tsunami threat. As a result of the EGDIA steps, the mass evacuation operation is divided into five phases, namely; pre-confirmation phase, tsunami-confirmed decision phase, evacuation phase, post-evacuation phase, return phase. Information requirements

are classified according to the roles and the phases of a mass evacuation operation, depending upon the tasks that need to be performed during each phase. These information requirements were validated via a questionnaire from emergency managers all over New Zealand. Very few additional comments were received and almost all the information requirements are declared relevant.

Based on these information requirements, the next stage involved the design of a computer based system. While reviewing the literature for technology solutions to improve situation awareness, ontology based situation awareness involving domain concepts and relationships was seen to offer a promising approach to the design process. Ontologies of tsunami situations and information requirements were therefore developed, along with information of roles and their tasks in the different emergency phases previously identified.

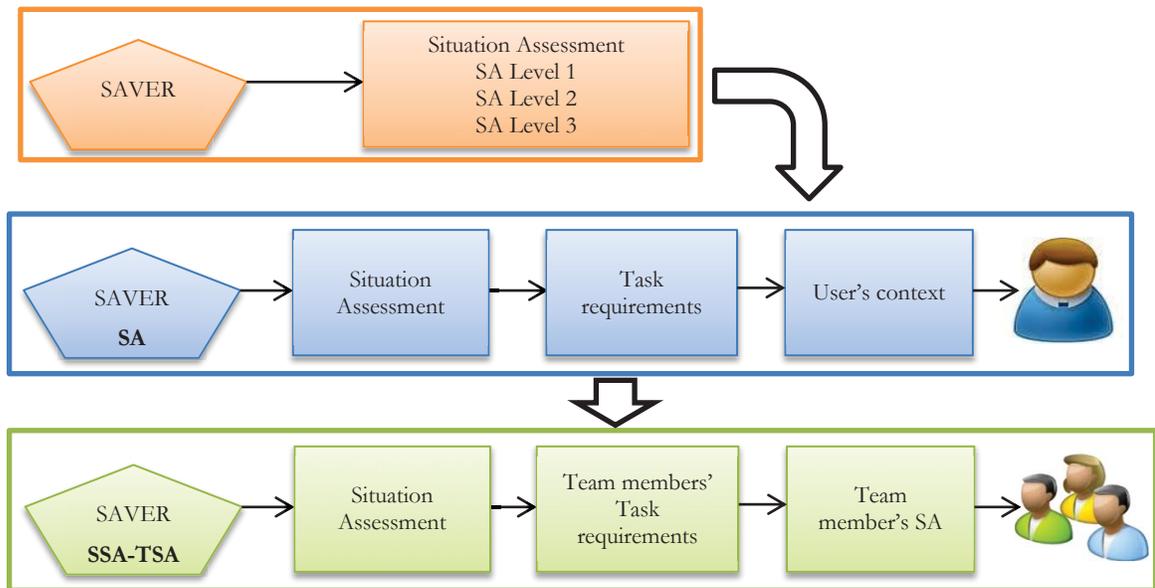
It is worth noting that existing ontology based SA systems only use the ontologies for modelling situations. However, the idea of the current research is to extend the existing ontology based SA to classify the situation information at Endsley's three levels of SA using an ontology reasoner (Fact Plus Plus) for Level 3 predictions. The idea led to the design of a systems architecture and the implementation of a proof-of-concept prototype labelled Situation Aware Vigilant Emergency Reasoner (SAVER).

The next phase employed SA-oriented design principles and a user centred design approach to develop a user interface for SAVER from which ontology based context reasoning provides personalised information to the various roles and so reduces information overload. SAVER was then evaluated in simulated experiments to see if it could improve the SA of the emergency managers. Situation Awareness Global Assessment Technique (SAGAT) was used to measure the SA of the participants obtained with and without SAVER. Results show that the SA of the SAVER users was significantly better than the non-SAVER users on all the SA levels. Moreover, the results illustrate that the SA of the less experienced emergency managers can also be improved to the level of the experienced emergency managers. Furthermore, the time taken by the SAVER users to retrieve SA for task use is also significantly shorter than the non-SAVER users, hence improving the efficiency of task performance.

For large emergency management operations, team co-ordination is very important for successful performance of the collaborative tasks. To work in an harmonious way, the

team members need to share the information within the team in a timely manner. The ability to co-ordinate decisions and tasks depends upon the degree of shared situation awareness (SSA) that team members have about the related information requirements of their colleagues. SAVER supports SSA by proactively reminding every team member about the SA requirements of team members that depend upon him/her. The SSA of the participants was measured along with their individual SA measurement. Results indicate the SSA of the SAVER users is significantly superior to the non-SAVER users.

Moreover, individuals in the team support their team members by successfully performing their own tasks or by contributing to other team member's tasks. Therefore, by improving an individual's SA, SAVER also improves this form of team SA (TSA). Another form of TSA, needed for the team decision making, is the common understanding of the situation. SAVER improves this understanding in three ways. Firstly, by providing the explicit situation assessment, secondly, by sharing a related team member's SA, and thirdly, by improving the individual SA. One more form of TSA is a team member's degree of awareness about the other members' situation awareness. This is required so that the other team members' SA can be updated or supported, if required. SAVER supports this form of TSA by improving the common understanding of a situation, by providing explicit situation assessment and by sharing the team member's SA. All these forms of TSA are measured in simulated experiments with and without using SAVER. Results prove that the TSA of the SAVER users in all forms of TSA is significantly larger than the non-SAVER users, individually and as a team. Figure 7.5 summarizes the evolution of SAVER through the three chapters (4-6) of this thesis.



**Figure 7.5 SAVER's evolution to support SSA and TSA**

Briefly, EGDIA proves to be very useful in gathering comprehensive information requirements and the use of ontologies is helpful for designing computer systems supporting SA, SSA and TSA. Ontologies can be used for computer based automatic situation assessment and so such a system can be used for supporting human SA. Furthermore, SA-oriented computer system design using precise information requirements improves the SA, SSA and TSA of the emergency managers. Use of a computer based SA improves the effectiveness and efficiency of the individual and team decision making by allowing them to make informed decisions in a short period of time. Additionally, a system with contextualised information improves the team co-ordination and collaboration required in large scale operations such as a mass evacuation, consequently improving the overall emergency management.

Chapter 8 contains recommendations for future work that will explore the implications of developing SAVER for emergency management and applying the concept to other domains.

# Chapter 8

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## SUMMARY, CONCLUSIONS AND FUTURE WORK

*“Each problem that I solved became a rule, which served afterwards to solve other problems”  
(Rene Descartes)*

This chapter provides a summary of the discoveries and other outcomes of the research work described in this thesis. It also includes the main conclusions associated with the points made. More detailed information on the conclusions is contained in the Discussion (Chapter 7).

### 8.1 Research Questions Answered

This first section demonstrates the scope and success of the research by reiterating the research questions and describing how they were answered. Cross references are given to the sections in the thesis where the relevant issues are discussed in full.

#### 8.1.1 How to design a computer based system for automatic situation assessment based on situation awareness (SA) requirements in emergency situations?

Chapter 4 of the thesis explains the design of a computer based system (SAVER) to support emergency managers in mass evacuation operations. Information requirements of the emergency managers to develop and maintain SA are gathered for the various emergency management roles. Moreover, a method to classify the incoming information according to the requirements of the emergency managers and the levels of SA is devised.

- a. How is SA developed in emergency situations?

An extensive review of the literature is carried out to understand SA development and its implications for emergency situations. Relevant literature is covered in Section 2.4 of Chapter 2, to describe the theoretical underpinning of the concept and various

processes involved in the SA development. However, the various systems supporting SA are discussed in Section 2.6.3 of Chapter 2.

- b. How to acquire the dynamic information needed for developing and maintaining situation awareness (SA)?

Extended Goal Directed Information Analysis (EGDIA) is used to gather the information requirements of developing and maintaining SA. It is a cognitive task analysis (CTA) technique since the information requirements for the cognitive processes are also captured along with the physical task. This method was quite successful in gathering the comprehensive information requirements. Details of this technique and the resulting information requirements are described in Chapter 4, Section 4.4.1.

- c. How to classify the information requirements according to the SA levels and the phases of an emergency situation?

Firstly, a mass evacuation operation is divided into five different phases covered in Section 4.4.1.2 of Chapter 4. Secondly, the information requirements are classified according to the roles and phases of a mass evacuation operation. Moreover, the information requirements are also classified according to the three levels of SA (perception, comprehension and projection) to determine what information is required to develop each level of SA. For automatic classification of the SA information, ontologies of a tsunami situation (domain ontology) and the information requirements are developed. An ontology reasoner (Fact plus plus) is used for the validation and classification of the ontologies. The architecture design of an ontology based SA is covered in section 4.5 of Chapter 4.

- d. Whether ontologies can be used to classify SA information or not?

The study demonstrated that ontologies can be used to classify the SA information. Since they can model the situations in great detail, the use of rules and axioms allows the inference required for the classification of elements as class types. Moreover, the classification of SA information was tested for the simulated scenarios. Ontology based reasoning successfully provided the automatic situation assessment according to the SA levels. Details of the evaluation are in section 4.5 of Chapter 4.

### **8.1.2 How to design a computer based system supporting human SA in mass evacuation operations?**

Chapter 5 of the thesis explains the user interface design of the computer based system (SAVER) to support human SA in mass evacuation operations. On the one hand, user interfaces are designed to provide the support to human SA, and on the other, the same interfaces are used to see if computer based systems can improve the SA of individuals in emergency situations. The SA of the emergency managers is improved on all three levels by providing them with the information needed to develop the SA necessary for decision making and task completion according to their roles.

#### **a. How to design a user interface for a computer based system supporting SA?**

The user interface of the computer based SAVER system is designed using the SA oriented design principles. The most important of these design principles is about delivering the processed information directly for developing SA Level 2 and Level 3 awareness. Details of these design principles and user interfaces are provided in Chapter 5, sections 5.4.3 and 5.4.4 respectively.

#### **b. How to reduce the information overload of emergency managers?**

The information overload of emergency managers can be minimised by providing the personalised information according to the roles and tasks they perform. For this purpose, the context information regarding the emergency managers, their roles, responsibilities and tasks are modelled in ontologies. These ontologies, along with the ontologies developed in Chapter 4 for tsunami situations (domain ontology) and the information requirements, are used to provide the personalised information to the emergency managers. Ontology based context design is explained in section 5.4.2 of Chapter 5.

#### **c. Whether a computer based system can improve SA of emergency managers?**

The study demonstrated that a computer based system can improve the SA of emergency managers in emergency situations. This is confirmed by measuring the SA of emergency managers using a technique called Situation Awareness Global Assessment Technique (SAGAT). The SA of emergency managers was measured using, and without using, the computer based system and the scores were compared. The reason for

measuring SA was twofold, first to check whether SA can be improved using computer based systems, and secondly, to evaluate the design of the computer based system developed for SA support. After the evaluation, it is confirmed that the developed system is very useful in improving the SA of emergency managers. Details of the SA measure and the evaluation of the computer based system are reported in the section 5.5 of Chapter 5 and discussed in section 7.5 of Chapter 7.

- d. How to evaluate the user interface design developed for computer based system supporting SA?

Apart from the evaluation by measuring individual SA, user interfaces are also evaluated for the human computer interaction (HCI) parameters like usability, e.g. ease of use, understandability, learnability, functionality, etc. All interfaces were positively evaluated by the emergency managers and very few modifications were suggested. Details of the HCI evaluations are reported in section 5.5.3 of Chapter 5.

### **8.1.3 How to design a computer based system supporting shared and team SA (SSA and TSA) of the emergency managers in mass evacuation operations?**

Chapter 6 describes the design, development, and evaluation of a computer based system to support the SSA and TSA of emergency managers in mass evacuation operations.

- a. How are SSA and TSA developed for decision making and collaborative tasks?

SSA is improved by reminding every team member about the requirements of other team members who are dependent upon them. Similarly, TSA is developed by sharing the team members' understanding of the situation with other relevant team members. Moreover, TSA as a common understanding of the situation, is also developed by providing the explicit situation assessment with logical arguments and improving the individual SA. Lastly, TSA as a belief about the team members' SA, is developed by improving the common understanding of the situation. Details of SSA and TSA development are covered in section 2.5 of Chapter 2, section 6.4.1 of Chapter 6 and sections 7.6 and 7.7 of Chapter 7.

b. How can ontology based contextual information be used to improve SSA, and TSA?

Contextual information is used to identify which team members are working on the same goals and tasks. Moreover, it can be used to understand which information is required by various roles for different tasks. Hence, the source and destination of the information can be used to improve their SSA by reminding the source to supply information manually to the destination thereby improving the recipient's SA. Similarly, TSA can be improved by automatically identifying the common goals and tasks, that will answer "whose SA needs to be shared with whom?" Like automatic situation assessment, automatic context reasoning is done using ontology based reasoning. Ontology based SSA and TSA oriented design is presented in section 6.4.2 of Chapter 6.

c. Whether a computer based system can improve the SSA and TSA of emergency managers?

A computer based system can significantly improve the SSA and TSA of emergency managers in emergency situations. This result is established by measuring the SSA and TSA of managers in the simulated experiments using, and without using, a computer based system. The measured SSA and TSA are significantly better when SAVER is used. Details of SSA and TSA measurement and the evaluation of the computer based system are reported in section 6.5 of Chapter 6 and discussed in sections 7.6 and 7.7 of Chapter 7.

## **8.2 Future Work**

Due to the myriad applications where SA, SSA and TSA are important, this study has widespread utility and potentially enormous impact. To conclude, we illustrate some of the key fields that can make use of research results with little extension.

### **8.2.1 Option Awareness**

In emergency situations, once the required level of SA, SSA and TSA is achieved the decision makers have to plan an action to normalise the situation. The action(s) comes from the different choices known to the decision makers. Clearly, knowledge, or lack of it, of the options, can affect the quality of the decisions made. This option knowledge is called option awareness (Pfaff et al., 2010). Hence, like situation awareness, option awareness can also be improved by extending SAVER to analyse various options according to the prevailing situation. The architecture of such systems can use automatic situation assessment by SAVER to improve option awareness by presenting options to

managers and recommending (but not deciding) preferred alternatives with reasons and consequences. A complete package for effective and efficient decision making could be developed.

Related to option awareness, further research is needed to understand the impact of computer based systems on the quality of decisions and the tasks performed. This would help to develop an in-depth understanding of the relationship between the degree of SA and the variation in quality of decisions and outcomes. Moreover, option awareness can provide a link between the degree of situation awareness and the quality of decision made.

### **8.2.2 Agents and Trust**

With the advent of computer based SA systems, a framework is needed for defining the SA of computer agents. This will help to identify the attributes of computer agents who possess SA capability and the capability to improve it. More work is needed to study the extent to which computer based SA can be used and trusted in real life scenarios. It was noticed that in the simulated experiments emergency managers seemed to accept the suggestions of computer based systems but in actual events the situation may be very different. Hence, research is needed to identify those attributes that can improve trust. Work is even needed to find the extent to which human decision makers trust computer based systems.

A more recent theme to emerge in the SA literature is the concept of distributed or systemic SA. Distributed SA (DSA) approaches are born out of distributed cognition theory (Hutchins, 1995), which describes the notion of joint cognitive systems comprising the people in the system and the artefacts they use. Within such systems, cognition is achieved through co-ordination between the system units (Artman & Gabris, 1998). DSA approaches therefore, view TSA not as a shared understanding of the situation, but rather as an entity that is separate from team members and is in fact, a characteristic of the whole system. The SA of a team is distributed not only throughout the agents comprising them, but also in the artefacts they use in order to accomplish their goals. Therefore, it would be useful to consider SAVER as part of an overall system and evaluate the interaction of various human and computer agents within the system.

The efficiency of the ontology based systems is also a question since even the latest ontology reasoners have problems in classifying large and complex ontologies. More research is needed to improve the efficiency of ontology based reasoning. Moreover, standard methods are needed for the development and maintenance of large and complex ontologies.

### **8.2.3 Integration of various disaster management sectors; health, fire, police**

The current architecture of SAVER is designed in a way that it can be extended to other disaster management sectors like health, police, fire service etc., to provide one system for all. Since in most large scale operations these organizations work together, an extensive requirements analysis can be done to identify their information and organisational needs. These requirements can be analysed to reveal the shared and team SA requirements. Having a single integrated system has many advantages such as standardised communication between organisations/departments and the development of an overall situation picture that will also help to improve SSA and TSA.

Rules and axioms of ontologies can be used to define which information to share and when. In this way, an overall integrated system composed of small individual systems can be developed. Such a system can fulfil local requirements and at the same time allow inter-operability on a regional, national or global scale. Moreover, the information integration from diverse sources, including web sources, will provide a better overall picture to the decision makers by acquiring the information from any possible valid source. Emergency management plans and guides can also be made part of such systems for automatic planning support.

### **8.2.4 Training of emergency managers**

A system like SAVER can be very useful for the training of emergency managers. It can be used to create various simulated scenarios and to generate information flows between various roles. Emergency managers can be trained for various possible situations. In addition, their performance can be measured by measuring their SA and improvement in their performance can be monitored over time. By changing different factors, e.g. information presentation styles, stress levels, available time etc., various behavioural studies can be performed to disclose different problems of emergency decision making. Various solutions for complex problems can also be tested or evaluated, as this study does.

### **8.2.5 Extension to mobile technologies**

In recent years, with the rapid growth of wireless and mobile technologies, users can make use of advanced technologies on the go, with no time or location constraints (Wang et al., 2009). This effective connection allows them to remain aware of the situation all the time. Moreover, if they are in the field, they can use various features of mobile devices, e.g. cameras, to add pictorial and audio information to the computer based system that can be shared to improve the situation awareness of the whole team of decision makers. Lai et al., (2007) studied the affordance of mobile technologies compared to desktop computers for real time information capture (wherever and whenever) and rapid transmission to corporate systems. They found the mobile aspect of considerable value and its application to emergencies (provided a broadband service is still available) is very clear. The extension of SAVER to mobile technologies can be done by expanding the context ontologies of SAVER with the features of mobile devices and adding the use methods for the integration of information from them.

### **8.2.6 Business decision making**

Many emergency decision making theories came from the background of business and defence (military) decision making. This is not a one way transfer. The digitisation and computerisation of emergency management tools can now be directed to business decision making and even to the re-engineering of business processes. Business decisions can be enhanced by improving the situation awareness of the decision makers. In addition, business decision making frequently emphasises costs, benefits and risks and modelling business decisions with ontologies can provide different and more complete perspectives leading to greater efficiency, better collaboration and competitive advantage.

### **8.2.7 Military applications**

Like emergencies, the decision making environment in battlefields is very complex and dynamic since many different factors are in action. War gaming and emergency training scenarios have much in common including the need for rapid decision making in dynamic situations that demand high levels of situation awareness. Ontology based reasoning can be applied to those situations when it may be difficult to identify the factors (or options) of relevance to a situation. Similarly, in such scenarios, it may also be unclear how the information relevant to a particular factor should be analysed, operationalised and characterised making it difficult to interpret the significance of information in terms of its impacts on mission objectives. An ontology based design

such as SAVER could be of considerable value in the military domain to improve situation awareness with consequent benefits for personnel deployment, resource preservation, concerted action and the execution of strategy.

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# APPENDIX A

## Research Information Sheet



Institute of Information and  
Mathematical Sciences  
Massey University, Albany  
Auckland.

### PARTICIPANT INFORMATION SHEET

Research project: Supporting Mass Evacuation: Using Ontology to Improve Shared Situation Awareness

My name is Yasir Javed. I am a PhD student at Massey University, Auckland. I am conducting research for the above named thesis.

Situation Awareness (SA) is a critical element of emergency decision making where time and information needed to make decisions are insufficient and lives are at stake. Better SA can improve operational effectiveness by facilitating the planning process improving the quality and timeliness of decisions, and by providing better feedback about the consequences of early actions. The biggest challenge in improving SA is to improve the shared SA of the team involved in the emergency decision making response. Team members with different environmental, personal, social, task and spatial-temporal contexts make it challenging to provide a single system for all members. We will analyse how semantic technologies might be used to address these challenges. We suggest that an approach featuring domain ontologies, reasoning capabilities, semantic queries and semantic integration techniques, provides the basis for an integrated framework for improving shared SA of a team.

You are invited to participate in my research and I would appreciate any assistance you can offer me. There is absolutely no obligation to participate and all the information will be held in the strictest confidence. If you do consent to participate, you may withdraw from the research project at any time without giving reason. All identifiable data will be destroyed on completion of the thesis and will be stored in a locked filing cabinet and destroyed six years after the project is completed.

The research will be in two parts:

a) Questionnaire

Firstly, a short interview questionnaire with some supplementary questions will be conducted prior the interview. It is expected that this questionnaire would take around 15 minutes to complete.

b) Interviews

Your participation would involve one to one interview. Interviews would take about 45 minutes, and be conducted during your own convenience. I would prefer to audio tape the interview but this would only be done with your consent and could be turned off at any time or you can withdraw information at any time.

If you are interested in participating, please let me know by filling in the attached Consent Form and sending it to me at the address given. If you prefer this can be done by email. All information you

*Note: This project has been evaluated by peer review and judged to be a low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher named above is responsible for the ethical conduct of this research.*

provide is confidential and your name will not be used. All participants will be sent an email copy of the results of the research if they desire. I will be pleased to provide you with the copy of final results of the research at no cost if you desire.

I would be grateful if you could indicate approval for your participation by filling the attached consent form and sending it to me.

Thank you very much for your time and help in making this study possible. If you have any queries or wish to know more please phone me on 02102735279 or write me at:

**Yasir Javed**

C/O Professor Tony Norris  
Institute of Information and Mathematical Sciences  
Massey University, Albany, Auckland.  
Private bag 102 904  
North Shore Mail Centre, Auckland  
Office: 094140800 ext: 9248  
Mobile: 02102735279  
Email: [y.javed@gmail.com](mailto:y.javed@gmail.com)

My supervisor and Head of Department: **Professor Tony Norris**

Institute of Information and Mathematical Sciences  
Massey University, Albany, Auckland.  
Private bag 102 904  
North Shore Mail Centre, Auckland  
Office: 094140800 ext: 9248

*Note: This project has been evaluated by peer review and judged to be a low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher named above is responsible for the ethical conduct of this research.*

*If you have any concerns about the conduct of this research that you wish to raise with someone other than the researcher, please contact Professor Sylvia Rumball, Assistant to the Vice Chancellor (Ethics and Equity), telephone 06 350 5249, email: [humanethicspn@massey.ac.nz](mailto:humanethicspn@massey.ac.nz)*

*Note: This project has been evaluated by peer review and judged to be a low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher named above is responsible for the ethical conduct of this research.*

# APPENDIX B

## Participation Consent Form



Institute of Information and  
Mathematical Sciences  
Massey University, Albany  
Auckland.

### INDIVIDUAL CONSENT FORM

#### THIS CONSENT FORM WILL BE HELD FOR THE PERIOD OF SIX YEARS

Title: Research Project: Supporting Mass Evacuation: Using Ontology to Improve Shared Situation Awareness

Researcher: Yasir Javed

To: <Name>

I have been given and have understood an explanation of this research project. I have had an opportunity to ask questions and have them answered.

I understand that I may withdraw myself or any information traceable to me at any time without giving a reason, that identifiable data will be destroyed on completion of the thesis, and will be stored in a locked filing cabinet and destroyed six years after the project is completed

I agree to take part in this research project

I agree to: (please select all that apply)

Be interviewed

Interview – I agree that interview may be audio taped<sup>1</sup> (Yes / NO)

be observed during exercise Tangaroa

Signed:

Name:

Title

Organization:

Email address:

Date:

|

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<sup>1</sup> Transcripts will be made from the taped information by the researcher. Draft transcripts will be circulated to participants. Participants will be given opportunity to withdraw any comments from the transcripts. Tapes will be erased once final transcripts are agreed.

*Note: This project has been evaluated by peer review and judged to be a low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher named above is responsible for the ethical conduct of this research.*

# APPENDIX C

## Low Risk Research Approvals



MASSEY UNIVERSITY

6 October 2010

Yasir Javed  
38 Borneo Drive  
Fairview Heights  
NORTH SHORE CITY 0632

Dear Yasir

**Re: Supporting Mass Evacuation: Using Ontology for Context-Based Shared Situation Awareness**

Thank you for your Low Risk Notification which was received on 6 October 2010.

Your project has been recorded on the Low Risk Database which is reported in the Annual Report of the Massey University Human Ethics Committees.

The low risk notification for this project is valid for a maximum of three years.

Please notify me if situations subsequently occur which cause you to reconsider your initial ethical analysis that it is safe to proceed without approval by one of the University's Human Ethics Committees.

Please note that travel undertaken by students must be approved by the supervisor and the relevant Pro Vice-Chancellor and be in accordance with the Policy and Procedures for Course-Related Student Travel Overseas. In addition, the supervisor must advise the University's Insurance Officer.

**A reminder to include the following statement on all public documents:**

*"This project has been evaluated by peer review and judged to be low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher(s) named above are responsible for the ethical conduct of this research.*

*If you have any concerns about the conduct of this research that you wish to raise with someone other than the researcher(s), please contact Professor John O'Neill, Director (Research Ethics), telephone 05 350 5249, e-mail humanethics@massey.ac.nz".*

Please note that if a sponsoring organisation, funding authority or a journal in which you wish to publish requires evidence of committee approval (with an approval number), you will have to provide a full application to one of the University's Human Ethics Committees. You should also note that such an approval can only be provided prior to the commencement of the research.

Yours sincerely

John G O'Neill (Professor)  
**Chair, Human Ethics Chairs' Committee and  
Director (Research Ethics)**

cc Prof Anthony Norris  
Institute of Information and Mathematical  
Sciences  
Albany

Assoc Prof David Johnston  
School of Psychology  
Wellington

Assoc Prof Mandy Morgan, HoS  
School of Psychology  
PN320

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Massey University Human Ethics Committee  
Accredited by the Health Research Council

Te Kaitiaki  
ki Pākehura

Research Ethics Office, Massey University, Private Bag 11222, Palmerston North 4442, New Zealand  
T +64 6 350 5573 +64 6 350 5575 F +64 6 350 5622  
E humanethics@massey.ac.nz animalethics@massey.ac.nz gtc@massey.ac.nz  
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Date 1 September 2010

Research Office  
Level 14, Support Bldg  
Auckland City Hospital  
PB 92024, Grafton, Auckland  
Phone: 64 9 307 4949 Extn. 23854  
Fax: 64 9 307 8913  
Email: [mwoodnorth@adhb.govt.nz](mailto:mwoodnorth@adhb.govt.nz)  
Website: [www.adhb.govt.nz/ResearchOffice](http://www.adhb.govt.nz/ResearchOffice)

**Institutional Approval**

Mr Yasir Javed  
38 Borneo Drive  
Fairview Heights  
North Shore City  
0632

Dear Yasir

Re: Research project A+4879 (No Ethics Required) Supporting mass evacuation: using ontology for context-based shared situation awareness

The Auckland DHB Research Review Committee (ADHB-RRC) would like to thank you for the opportunity to review your study and has given approval for your research project.

Your Institutional approval is dependant on the Research Office having up-to-date information and documentation relating to your research and being kept informed of any changes to your study. It is your responsibility to ensure you have kept Ethics and the Research Office up to date and have the appropriate approvals. ADHB approval may be withdrawn for your study if you do not keep the Research Office informed of the following:

- Any communication from Ethics Committees, including confirmation of annual ethics renewal
- Any amendment to study documentation
- Study completion, suspension or cancellation

More detailed information is included on the following page. If you have any questions please do not hesitate to contact the Research Office.

Yours sincerely

On behalf of the ADHB Research Review Committee  
Dr Mary-Anne Woodnorth  
Manager, Research Office  
ADHB

c.c.

# APPENDIX D

## General Interview questions



### Interview questions:

1. What is your role in emergency management? (Any of CIMS role e.g. Controller, Operations Manager, Logistic Manager, Planning & Intelligence Manager, Media)
2. What are the activities/tasks associated with your role?
3. What are the tasks (sub-processes) related to above mentioned activities?
4. What are the goals of each of these activities and tasks?
5. Considering the goals what information is needed to achieve every goal?
6. Who is supplier of that information?
7. How you obtain this required information?
8. How you use this information?
9. What are the problems in understanding the new information?
10. How you manage to fit the new information in existence knowledge base?
11. How you figure out that this information is relevant and this is not in current situation?
12. What are the results of or outputs of at your tasks or process?
13. Who are the possible consumers of the outputs in previous question?
14. Can you briefly point out additional activities e.g. relevant to involved stakeholders, communications etc that you think are important for your activities and tasks?
15. What kind of decisions you made while performing your activities?
16. While performing the activities what are the key elements on which you based your decisions?
17. Can you prioritize the elements?
18. How do you identify the relevant information or information elements that can be useful for your decision?
19. How do you relate this information to that specific situation of emergency or how you draw meaning of this information in relevance to that emergency situation?
20. How do you use this information to project the future states of situation to make decisions? (Predictions)
21. Which factors do you think have affected your activities? Any examples?
22. Any suggestions to improve the process?

# APPENDIX E

## Templates Used for Information Requirements Gathering



**Massey University**

Institute of Information and  
Mathematical Sciences Massey  
University, Albany, Auckland.

### Template for gathering Information Requirements

#### (Group Operations Manager)

**Note:** By filling this Questionnaire you are consenting to the information provided in information sheet and consent form.

Please answer the questions asked in black about the **Tasks** mentioned in **blue**. You can leave questions blank if you want but it would be highly appreciated if you answer the questions to the best of your knowledge. For any question please feel free to contact the primary researcher at [y.javed@massey.ac.nz](mailto:y.javed@massey.ac.nz)

Please answer the following questions for all the tasks mentioned below in below:

1. How you will perform the above mentioned task?
2. What information is required to perform the task?
3. Where you will look for this information? Please mention some of the sources.

**Task 1:** Provide planning / Intelligence Manager/ Section with objectives for Action Planning meetings and provide information for ~~Sitrops~~

**Task 2:** Ensure deadlines / timelines and actions are met

**Task 3:** Establish communication methods with LEOCs, Local Controllers, NCMC etc

**Task 4:** Establish a system for incoming messages and transmitting of outward messages

**Task 5:** Process and register correspondence, operational messages and internally generated directives and distribute to the appropriate sections

**Task 6:** Liaise with Planning / Intelligence section to ensure all actions have been carried out

**Task 7:** Get all important new information and requests. Disseminate to the appropriate section immediately. |

**Template for gathering Information Requirements****(Group Controller)**

**Note:** By filling this Questionnaire you are consenting to the information provided in information sheet and consent form.

Please answer the questions asked in black about the **Tasks** mentioned in blue. You can leave questions blank if you want but it would be highly appreciated if you answer the questions to the best of your knowledge. For any question please feel free to contact the primary researcher at [y.javed@massey.ac.nz](mailto:y.javed@massey.ac.nz)

Please answer the following questions for all the tasks mentioned below in below:

1. How you will perform the above mentioned task?
2. What information is required to perform the task?
3. Where you will look for this information? Please mention some of the sources.

**Task 1: Order the appropriate level of activation of the Group EOC**

**Task 2: Determine what GEOC functions are required and contact appropriate personnel for initial activation**

**Task 3: Determine if/what representation is needed from support agencies in the GEOC Liaison Function**

**Task 4: Ensure all the supporting agencies and organizations are informed of the current situation**

**Task 5: Set initial priorities for the GEOC based on the information received from the local Controllers and other supporting agencies**

**Task 6: Set Specific objectives; forecast the relationship between the needs and resources and resource availability from a regional perspective; set resource allocation priorities**

**Task 7: Set GEOC operational periods**

**Task 8: Review, approve and authorise the implementation of the Action plan once completed by Planning / Intelligence**

**Task 9: Approve release of Sitreps and media reports**

**Task 10: Brief and liaise with Group Recovery Manager**

**Task 11: Ensure risk management principles and procedures are applied for all GEOC activities**

**Task 12: Approve resource requests not included in the Action plan, as required**

**Task 13: Assign in writing, delegated powers allowed under declaration if any are given**



## Template for gathering Information Requirements

### (Group Planning and Intelligence Manager)

Note: By filling this Questionnaire you are consenting to the information provided in information sheet and consent form.

Please answer the questions asked in black about the **Tasks** mentioned in **blue**. You can leave questions blank if you want but it would be highly appreciated if you answer the questions to the best of your knowledge. For any question please feel free to contact the primary researcher at [y.javed@massey.ac.nz](mailto:y.javed@massey.ac.nz)

Please answer the following questions for all the tasks mentioned below in below:

1. How you will perform the above mentioned task?
2. What information is required to perform the task?
3. Where you will look for this information? Please mention some of the sources.

Task 1: Develop situation report (SitRep)

Task 2: Maintain situation boards and displays in timely manner

Task 3: Liaise with technical experts

Task 4: Conduct advance planning and risk assessment

Task 5: Prepare warnings

Task 6: Identify new intelligence critical to the overall outcomes

Task 7: Liaise as appropriate to gather best understanding of information / situation

Task 8: Develop incident action plan (IAP)

Task 9: Validate received information

Task 10: Determine potential future impacts and risks of the event

**Template for gathering Information Requirements****(Group Logistics Manager)**

**Note:** By filling this Questionnaire you are consenting to the information provided in information sheet and consent form.

Please answer the questions asked in black about the **Tasks** mentioned in blue. You can leave questions blank if you want but it would be highly appreciated if you answer the questions to the best of your knowledge. For any question please feel free to contact the primary researcher at [y.javed@massey.ac.nz](mailto:y.javed@massey.ac.nz)

Please answer the following questions for all the tasks mentioned below in below:

1. How you will perform the above mentioned task?
2. What information is required to perform the task?
3. Where you will look for this information? Please mention some of the sources.

**Task 1:** Prioritise the allocation of resources in accordance to the response and recovery priorities established by the Group Controller

**Task 2:** Recording of all offers of organizational support from within and outside

**Task 3:** Coordination of transport for response and recovery in liaison with Planning and Intelligence and the Group Controller

**Task 4:** The acquisition and management of the support requirements from Local Emergency Operation Centres (LEOCs).

**Tasks 5:** Advance planning for future logistic requirements

**Tasks 6:** Provide LEOCs with logistical information

**Task 7:** The acquisition and allocation of resources

**Task 8:** Provide finance section with the purchase order information

**Task 9:** Ensure that all financial and purchasing records are maintained throughout the event or emergency

**Task 10:** Maintain system of tracking resources to identify if they are available, assigned or not available

**Task 11:** Ensure all resource requests are assigned the appropriate priority level e.g. Urgent, Priority, Routine.



## Template for gathering Information Requirements

### (Group Welfare Manager)

Note: By filling this Questionnaire you are consenting to the information provided in information sheet and consent form.

Please answer the questions asked in black about the **Tasks** mentioned in **blue**. You can leave questions blank if you want but it would be highly appreciated if you answer the questions to the best of your knowledge. For any question please feel free to contact the primary researcher at [y.javed@massey.ac.nz](mailto:y.javed@massey.ac.nz)

Please answer the following questions for all the tasks mentioned below in below:

1. How you will perform the above mentioned task?
2. What information is required to perform the task?
3. Where you will look for this information? Please mention some of the sources.

**Task 1: Maintain an overview of affected people and complete the impact assessment form.**

**Task 2: Coordinate and consolidate reports for inclusion in situation reports (SitReps).**

**Task 3: Ensure action plan tasks are completed and information is supplied to Planning and Intelligence for updated SitReps.**

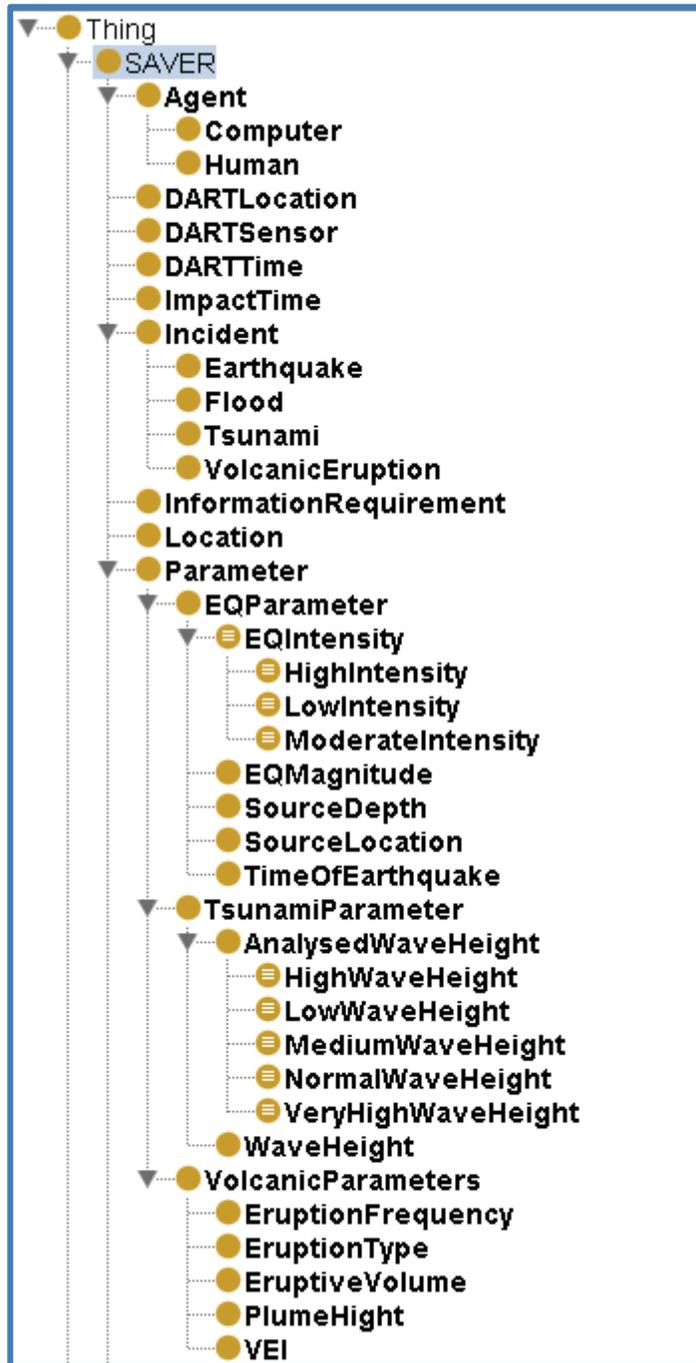
**Task 4: Provide an early focus on recovery issues.**

**Task 5: Develop Welfare status report**

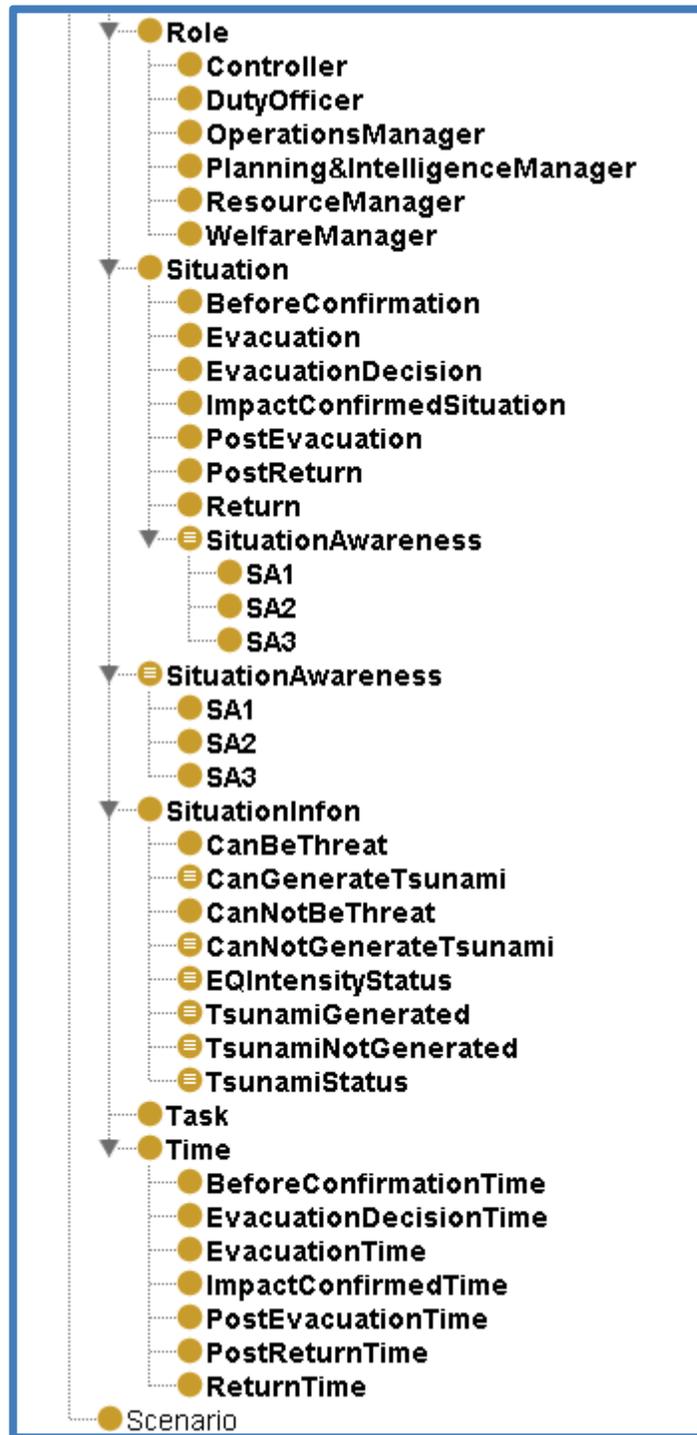
**Task 6: Maintain Welfare status board |**

# APPENDIX F

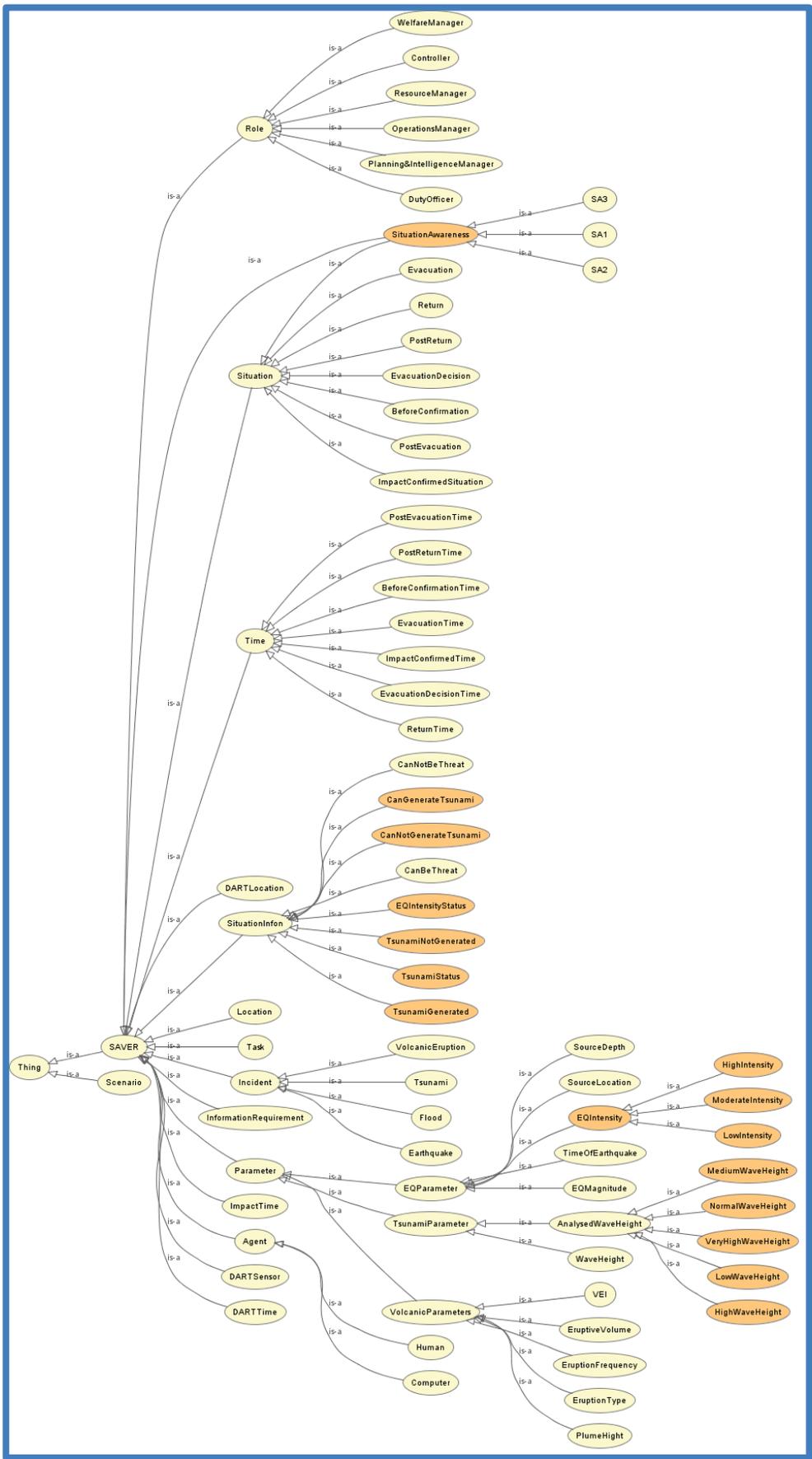
## Screenshots of the Ontologies Developed



Concepts of SAVER ontology as seen in Protégé editor (Part 1)

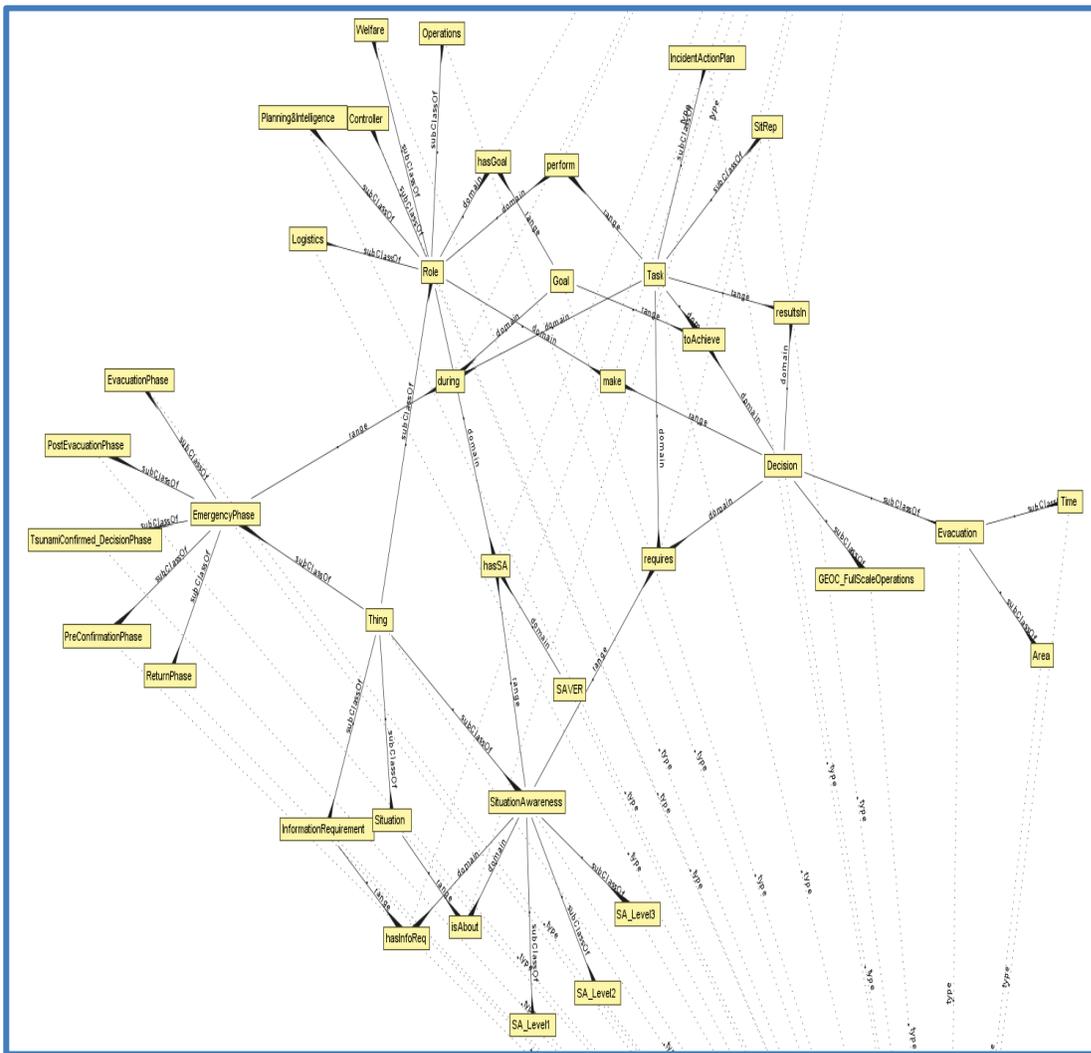


Concepts of SAVER ontology as seen in Protégé editor (Part 2)



Hierarchy of asserted SAVER ontology as seen in Protégé editor





Partial SAVER ontology showing relationships between concepts

# APPENDIX G

## Simulation Experiment Questions

### Part A:

AN EARTHQUAKE HAS OCCURRED WITH THESE PRELIMINARY PARAMETERS

ORIGIN TIME - 1334Z 01 APR  
COORDINATES - 15.0 WEST 115.0 NORTH  
LOCATION - MEXICO, NORTH PACIFIC OCEAN  
MAGNITUDE - 8.1  
Depth - 28 KM

### EVALUATION

IT IS NOT KNOWN THAT A TSUNAMI WAS GENERATED. THIS WARNING IS BASED ONLY ON THE EARTHQUAKE EVALUATION. AN EARTHQUAKE OF THIS SIZE HAS THE POTENTIAL TO GENERATE A DESTRUCTIVE TSUNAMI THAT CAN STRIKE COASTLINES NEAR THE EPICENTER WITHIN MINUTES AND MORE DISTANT COASTLINES WITHIN HOURS. AUTHORITIES SHOULD TAKE APPROPRIATE ACTION IN RESPONSE TO THIS POSSIBILITY. THIS CENTER WILL MONITOR SEA LEVEL DATA FROM GAUGES NEAR THE EARTHQUAKE TO DETERMINE IF A TSUNAMI WAS GENERATED AND ESTIMATE THE SEVERITY OF THE THREAT.

1. What was the magnitude of earthquake?  
\_\_\_\_\_
2. What was the depth of earthquake source?  
\_\_\_\_\_
3. What was the location of the earthquake source?  
\_\_\_\_\_
4. How well do you believe that you remembered the situation cues?
  - Perfectly
  - Sufficiently
  - Not enough
  - Not at all

5. According to your interpretation, earthquake magnitude is \_\_\_\_\_  
to generate a tsunami?
- Very high
  - High enough
  - Not high enough
  - Not high at all
6. According to your understanding of source depth and location, how likely it can  
cause a tsunami?
- Highly likely
  - Likely
  - Unlikely
  - Highly unlikely
7. According to your understanding of situation how likely it is that tsunami will be  
generated?
- Highly likely
  - Likely
  - Unlikely
  - Highly unlikely
8. What information / cues you perceived to understand the tsunami generation?  
Please list the cues you remember: \_\_\_\_\_
9. What do you require to understand / interpret the perceived cues? Or what have  
you used to understand or interpret the perceived information? Put number in  
front of options to rank.
- Experience \_\_\_\_\_
- SAVER's suggestion \_\_\_\_\_
- Communication with partner \_\_\_\_\_
- Other \_\_\_\_\_
10. Once you have the understanding of information cues, what information you  
needed to predict the tsunami generation?  
Please list all sources: \_\_\_\_\_

11. According to your belief what informational cues your team member should perceive to understand tsunami generation?  
Please list the cues you remember: \_\_\_\_\_
12. What do you think your team member requires for understanding / interpreting the perceived cues? Or what have your team member used to understand or interpret the perceived cues? Put number in front of options to rank. ASSA2  
Experience \_\_\_\_\_  
SAVER's suggestion \_\_\_\_\_  
Communication with partner \_\_\_\_\_  
Other \_\_\_\_\_
13. Once your team member has the understanding of information cues, what information he / she needed to predict the tsunami generation?  
Please list all sources: \_\_\_\_\_
14. What do you think your team member answered about magnitude, depth and location of earthquake?  
Magnitude \_\_\_\_\_  
Depth of source \_\_\_\_\_  
Location \_\_\_\_\_
15. How well do you believe that your team member remembered the situational cues?
- Perfectly
  - Sufficiently
  - Not enough
  - Not at all
16. How confident you feel about your answer for the above question?
- Highly
  - Somewhat
  - A little
  - Not much
  - Not enough
  - Not at all
17. What do you believe that B will rate magnitude as:

- Low
- High
- Moderate
- Don't know

18. According to your belief what your team member understands from source depth and location about the likelihood of tsunami generation?

- Highly likely
- Likely
- Unlikely
- Highly unlikely

19. According to your belief what is your team member's prediction about likelihood of tsunami generation?

- Highly likely
- Likely
- Unlikely
- Highly unlikely

20. How well do you believe that your team member believe how well you remembered the situational cues?

- Perfectly
- Sufficiently
- Not enough
- Not at all

21. How confident you feel about your answer for the above question?

- Highly
- Somewhat
- A little
- Not much
- Not enough
- Not at all

22. Do you believe that your team member marked the same options as you did?

- Highly agree

- Agree
- Not agree
- Don't agree at all

23. How confident you feel about your answer for the above question?

- Highly
- Somewhat
- A little
- Not much
- Not enough
- Not at all

24. Do you believe that your team member believe that you marked the same options as he / she did?

- Highly agree
- Agree
- Not agree
- Don't agree at all

25. How confident you feel about your answer for the above question?

- Highly
- Somewhat
- A little
- Not much
- Not enough
- Not at all

**Part B:**

DART sensors in the area provide the following wave information.

MEASUREMENTS OR REPORTS OF TSUNAMI WAVE ACTIVITY ISSUED AT T5 2305Z  
01 APR

GAUGE PER	LOCATION	LAT	LON	TIME	AMPL
-----	-----	-----	-----	-----	-----
----	----	----	----	----	----
240NM 14MIN	Manzanillo, Mexico	15.0N	110.0W	0244Z	1.31M = 4.3FT
360NM 22MIN	Acapulco, Mexico	12.0N	100.0W	0124Z	1.58M = 5.2FT
710NM 12MIN	Panama City, Panama	05.0N	090.0W	0135Z	1.88M = 6.2FT
400NM 40MIN	Southeast of Tonga	08.4S	125.0W	0040Z	1.09M = 3.6FT
640NM 62MIN	Auckland, New Zealand	33.0S	173.0W	2308Z	1.40M = 4.6FT

MEASUREMENTS OR REPORTS OF TSUNAMI WAVE ACTIVITY ISSUED AT T4 2135Z  
01 APR

GAUGE PER	LOCATION	LAT	LON	TIME	AMPL
-----	-----	-----	-----	-----	-----
----	----	----	----	----	----
240NM 14MIN	Manzanillo, Mexico	15.0N	110.0W	0244Z	1.37M = 4.5FT
360NM 22MIN	Acapulco, Mexico	12.0N	100.0W	0124Z	1.61M = 5.3FT
710NM 12MIN	Panama City, Panama	05.0N	090.0W	0135Z	1.92M = 6.3FT
400NM 40MIN	Southeast of Tonga	08.4S	125.0W	0040Z	0.97M = 3.2FT
640NM 62MIN	Auckland, New Zealand	33.0S	173.0W	2308Z	0.06M = 0.2FT

MEASUREMENTS OR REPORTS OF TSUNAMI WAVE ACTIVITY ISSUED AT T3 1855Z  
01 APR

GAUGE PER	LOCATION	LAT	LON	TIME	AMPL
-----	-----	-----	-----	-----	-----
----	----	----	----	----	----
240NM 14MIN	Manzanillo, Mexico	15.0N	110.0W	0244Z	1.34M = 4.4FT
360NM 22MIN	Acapulco, Mexico	12.0N	100.0W	0124Z	1.58M = 5.2FT
710NM 12MIN	Panama City, Panama	05.0N	090.0W	0135Z	1.95M = 6.4FT
400NM 40MIN	Southeast of Tonga	08.4S	125.0W	0040Z	0.06M = 0.2FT
640NM 62MIN	Auckland, New Zealand	33.0S	173.0W	2308Z	0.09M = 0.3FT

MEASUREMENTS OR REPORTS OF TSUNAMI WAVE ACTIVITY ISSUED AT T2 1627Z  
01 APR

GAUGE PER	LOCATION	LAT	LON	TIME	AMPL
240NM 14MIN	Manzanillo, Mexico	15.0N	110.0W	0244Z	1.24M = 4.1FT
360NM 22MIN	Acapulco, Mexico	12.0N	100.0W	0124Z	1.55M = 5.1FT
710NM 12MIN	Panama City, Panama	05.0N	090.0W	0135Z	0.03M = 0.1FT
400NM 40MIN	Southeast of Tonga	08.4S	125.0W	0040Z	0.09M = 0.3FT
640NM 62MIN	Auckland, New Zealand	33.0S	173.0W	2308Z	0.03M = 0.1FT

MEASUREMENTS OR REPORTS OF TSUNAMI WAVE ACTIVITY ISSUED AT T1 1346Z  
01 APR

GAUGE PER	LOCATION	LAT	LON	TIME	AMPL
240NM 14MIN	Manzanillo, Mexico	15.0N	110.0W	1340Z	1.28M = 4.2FT
360NM 22MIN	Acapulco, Mexico	12.0N	100.0W	0124Z	0.09M = 0.3FT
710NM 12MIN	Panama City, Panama	05.0N	090.0W	0135Z	0.06M = 0.2FT
400NM 40MIN	Southeast of Tonga	08.4S	125.0W	0040Z	0.09M = 0.2FT
640NM 62MIN	Auckland, New Zealand	33.0S	173.0W	2308Z	0.20M = 0.4FT

LAT - LATITUDE (N=NORTH, S=SOUTH)

LON - LONGITUDE (E=EAST, W=WEST)

TIME - TIME OF THE MEASUREMENT (Z = UTC = GREENWICH TIME)

AMPL - TSUNAMI AMPLITUDE MEASURED RELATIVE TO NORMAL SEA LEVEL.

IT IS ...NOT... CREST-TO-TROUGH WAVE HEIGHT.

IT IS ...NOT... CREST-TO-TROUGH WAVE HEIGHT.

VALUES ARE GIVEN IN BOTH METERS (M) AND FEET (FT).

PER - PERIOD OF TIME IN MINUTES (MIN) FROM ONE WAVE TO THE NEXT.

## EVALUATION

SEA LEVEL READINGS INDICATE A TSUNAMI WAS GENERATED. IT MAY HAVE BEEN DESTRUCTIVE ALONG COASTS NEAR THE EARTHQUAKE EPICENTER AND COULD ALSO BE A THREAT TO MORE DISTANT COASTS. AUTHORITIES SHOULD TAKE APPROPRIATE ACTION IN RESPONSE TO THIS POSSIBILITY. THIS CENTER WILL CONTINUE TO MONITOR SEA LEVEL DATA TO DETERMINE THE EXTENT AND SEVERITY OF THE THREAT.

FOR ALL AREAS - WHEN NO MAJOR WAVES ARE OBSERVED FOR TWO HOURS AFTER THE ESTIMATED TIME OF ARRIVAL OR DAMAGING WAVES HAVE NOT OCCURRED FOR AT LEAST TWO HOURS THEN LOCAL AUTHORITIES CAN ASSUME THE THREAT IS PASSED. DANGER TO BOATS AND COASTAL STRUCTURES CAN CONTINUE FOR SEVERAL HOURS DUE TO RAPID CURRENTS. AS LOCAL CONDITIONS CAN CAUSE A WIDE VARIATION IN TSUNAMI WAVE ACTION THE ALL CLEAR DETERMINATION MUST BE MADE BY LOCAL AUTHORITIES.

ESTIMATED INITIAL TSUNAMI WAVE ARRIVAL TIMES. ACTUAL ARRIVAL TIMES MAY DIFFER AND THE INITIAL WAVE MAY NOT BE THE LARGEST. THE TIME BETWEEN SUCCESSIVE TSUNAMI WAVES CAN BE FIVE MINUTES TO ONE HOUR.

ESTIMATED INITIAL TSUNAMI WAVE ARRIVAL TIMES ISSUED AT 1627Z 01 APR

LOCATION		COORDINATES	ARRIVAL TIME
-----		-----	-----
NEW ZEALAND	NORTH CAPE	34.4S 173.3E	0138Z 02 APR
	EAST CAPE	37.5S 178.5E	0214Z 02 APR
	AUCKLAND(W)	37.1S 174.2E	0238Z 02 APR
	GISBORNE	38.7S 178.0E	0247Z 02 APR
	MILFORD SOUND	44.5S 167.8E	0249Z 02 APR
	NEW PLYMOUTH	39.1S 174.1E	0310Z 02 APR
	NAPIER	39.5S 176.9E	0316Z 02 APR
	WESTPORT	41.8S 171.2E	0332Z 02 APR
	AUCKLAND(E)	36.7S 175.0E	0332Z 02 APR
	WELLINGTON	41.5S 174.8E	0333Z 02 APR
	BLUFF	46.6S 168.3E	0351Z 02 APR
	NELSON	41.3S 173.3E	0426Z 02 APR
	LYTTELTON	43.6S 172.7E	0439Z 02 APR
	DUNEDIN	45.9S 170.5E	0506Z 02 APR

ESTIMATED INITIAL TSUNAMI WAVE ARRIVAL TIMES ISSUED AT 1346Z 01 APR

LOCATION		COORDINATES	ARRIVAL TIME
-----		-----	-----
SOLOMON IS.	MUNDA	8.4S 157.2E	2039Z 01 APR
	FALAMAE	7.4S 155.6E	2103Z 01 APR
	PANGGOE	6.9S 157.2E	2120Z 01 APR
	HONIARA	9.3S 160.0E	2121Z 01 APR
	GHATERE	7.8S 159.2E	2122Z 01 APR
	AUKI	8.8S 160.6E	2134Z 01 APR

	KIRAKIRA	10.4S	161.9E	2140Z	01	APR
PAPUA NEW GUINE	AMUN	6.0S	154.7E	2124Z	01	APR
	KIETA	6.1S	155.6E	2133Z	01	APR
	RABAUL	4.2S	152.3E	2145Z	01	APR
	LAE	6.8S	147.0E	2218Z	01	APR
	KAVIENG	2.5S	150.7E	2223Z	01	APR
	MADANG	5.2S	146.0E	2241Z	01	APR
	PORT MORESBY	9.5S	147.0E	2254Z	01	APR
	MANUS IS.	2.0S	147.5E	2259Z	01	APR
	WEWAK	3.5S	143.6E	2325Z	01	APR
	VANIMO	2.6S	141.3E	2350Z	01	APR
VANUATU	ESPERITU SANTO	15.1S	167.3E	2236Z	01	APR
	ANATOM IS.	20.2S	169.9E	2322Z	01	APR
NEW CALEDONIA	NOUMEA	22.3S	166.5E	2338Z	01	APR
AUSTRALIA	CAIRNS	16.7S	145.8E	2349Z	01	APR
	BRISBANE	27.2S	153.3E	0033Z	02	APR
	SYDNEY	33.9S	151.4E	0114Z	02	APR
	GLADSTONE	23.8S	151.4E	0139Z	02	APR
	MACKAY	21.1S	149.3E	0144Z	02	APR
	HOBART	43.3S	147.6E	0245Z	02	APR
TUVALU	FUNAFUTI IS.	7.9S	178.5E	2359Z	01	APR
KIRIBATI	TARAWA IS.	1.5N	173.0E	0007Z	02	APR
	KANTON IS.	2.8S	171.7W	0121Z	02	APR
	CHRISTMAS IS.	2.0N	157.5W	0325Z	02	APR
	MALDEN IS.	3.9S	154.9W	0336Z	02	APR
	FLINT IS.	11.4S	151.8W	0408Z	02	APR
FIJI	SUVA	18.1S	178.4E	0038Z	02	APR
KERMADEC IS	RAOUL IS.	29.2S	177.9W	0131Z	02	APR
NEW ZEALAND	NORTH CAPE	34.4S	173.3E	0138Z	02	APR
	EAST CAPE	37.5S	178.5E	0214Z	02	APR
	AUCKLAND (W)	37.1S	174.2E	0238Z	02	APR
	GISBORNE	38.7S	178.0E	0247Z	02	APR
	MILFORD SOUND	44.5S	167.8E	0249Z	02	APR
	NEW PLYMOUTH	39.1S	174.1E	0310Z	02	APR
	NAPIER	39.5S	176.9E	0316Z	02	APR
	WESTPORT	41.8S	171.2E	0332Z	02	APR
	AUCKLAND (E)	36.7S	175.0E	0332Z	02	APR
	WELLINGTON	41.5S	174.8E	0333Z	02	APR
	BLUFF	46.6S	168.3E	0351Z	02	APR
	NELSON	41.3S	173.3E	0426Z	02	APR
	LYTTELTON	43.6S	172.7E	0439Z	02	APR
	DUNEDIN	45.9S	170.5E	0506Z	02	APR

1. What was wave height per \_\_\_\_\_ minute at sensor located at SAIPAN USA?

\_\_\_\_\_

2. What was wave height per \_\_\_\_\_ at sensor located at VANAUTA?

\_\_\_\_\_

3. How well do you believe that you remembered the situation cues?

- Perfectly
- Sufficiently
- Not enough
- Not at all

4. According to your interpretation of waves, wave height is \_\_\_\_\_  
to indicate the tsunami generation.
- Very high
  - High enough
  - Not high enough
  - Not high at all
5. According to your interpretation of wave heights, how likely is it that tsunami is generated?
- Highly likely
  - Likely
  - Unlikely
  - Highly unlikely
6. According to your understanding of wave travel direction, which areas are likely to be inundated?  
List as many you can remember: \_\_\_\_\_
7. According to your understanding of wave speed what is predicted arrival time of wave at Auckland coasts?  
Time: \_\_\_\_\_ OR Hours \_\_\_\_\_
8. What information / cues you should perceive to understand tsunami generation from wave information?  
Please list the cues you remember: \_\_\_\_\_
9. What do you require to understand from wave information that tsunami has been generated? Or what have you used to understand that tsunami has been generated? Put number in front of options to rank.
- Experience \_\_\_\_\_
- SAVER's suggestion \_\_\_\_\_
- Communication with partner \_\_\_\_\_
- Other \_\_\_\_\_
10. What do you require to understand / interpret the speed of waves? Or what have you used to calculate the speed of waves? Put number in front of options to rank.

Experience \_\_\_\_\_  
SAVER's suggestion \_\_\_\_\_  
Communication with partner \_\_\_\_\_  
Other \_\_\_\_\_

11. Once you have the understanding of information cues, what information you needed to predict the arrival time of tsunami wave on the coasts?  
Please list all sources: \_\_\_\_\_

12. Once you have the understanding of information cues, what information you needed to identify the areas under risk of inundation?  
Please list all sources: \_\_\_\_\_

13. According to your belief what informational cues your team member should perceive to understand tsunami generation?  
Please list the cues you remember: \_\_\_\_\_

14. What your team member requires to understand from wave information that tsunami has been generated? Or what have he / she used to understand that tsunami has been generated? Put number in front of options to rank.  
Experience \_\_\_\_\_  
SAVER's suggestion \_\_\_\_\_  
Communication with partner \_\_\_\_\_  
Other \_\_\_\_\_

15. Once your team member has the understanding of information cues, what information he / she need to predict the arrival time of tsunami wave on the coasts?  
Please list all sources: \_\_\_\_\_

16. What do you think your team member has answered about wave height at VANAUTA?  
Wave height: \_\_\_\_\_

17. How well do you believe that your team member remembered the situational cues?  
 Perfectly  
 Sufficiently

- Not enough
- Not at all

18. How confident you feel about your answer for the above question?

- Highly
- Somewhat
- A little
- Not much
- Not enough
- Not at all

19. What do you believe that B has rated wave height as \_\_\_\_\_ to indicate the tsunami generation?

- Very High
- High enough
- Not high enough
- Not high at all

20. According to your belief what your team member understands from wave information about the likelihood that tsunami is generated?

- Highly likely
- Likely
- Unlikely
- Highly unlikely

21. According to your belief what is your team member's prediction about wave arrival time at Auckland Coasts?

Time: \_\_\_\_\_ OR Hours \_\_\_\_\_

22. How well do you believe that your team member believe how well you remembered the situational cues?

- Perfectly
- Sufficiently
- Not enough
- Not at all

23. How confident you feel about your answer for the above question?
- Highly
  - Somewhat
  - A little
  - Not much
  - Not enough
  - Not at all
24. Do you believe that your team member marked the same options as you did?
- Highly agree
  - Agree
  - Not agree
  - Don't agree at all
25. How confident you feel about your answer for the above question?
- Highly
  - Somewhat
  - A little
  - Not much
  - Not enough
  - Not at all
26. Do you believe that your team member believe that you marked the same options as he / she did?
- Highly agree
  - Agree
  - Not agree
  - Don't agree at all
27. How confident you feel about your answer for the above question?
- Highly
  - Somewhat
  - A little
  - Not much
  - Not enough
  - Not at all