Design, Implementation and Evaluation of anEmergency Management System to Enhance Situation Awareness

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Abstract

Successful decision making and task execution in emergency management requiresappropriate levels of situation awareness (SA). This paper proposes an ontology-based model for the design of a computer-based system (SAVER) that supportsthe individual, shared and team SA of managers in emergency situations. SAVER is evaluated in simulated experiments to demonstrate its performance.

1 Introduction

Large-scale emergencies such as tsunamis or volcanic eruptions are managed by several teams, e.g. emergency managers, military, police, fire services, healthcare professionals, etc. Close coordination 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 coordination and decision making by presenting, structuring, processing, and interpreting huge amounts of information in a short space 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.

In this paper we describe the design, development, and evaluation of an information system dubbed Situation Aware Vigilant Emergency Reasoner (SAVER) based on SSA and TSA design principles. The paper first discusses SSA and TSA and shows how they are used to develop the SAVER design. It then describes the implementation of the design and the simulations carried out to evaluate SAVER. Finally, it discusses the results and makes suggestions for developing the prototype into a production system.

Role of SA, SSA and TSA in Emergency Management

The process of understanding a prevailing situation to achieve a set of goals is called situation assessment and this process results in a product named situation awareness (SA). SA is the degree to which each individual 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, 1995; Smith & Hancock, 1995).

As indicated, emergency managers usually work in teams and to function effectively, each team member must share a common understanding of a situation so that they can coordinate their decision making and actions. Different assessments of the situation can lead to uncoordinated 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 contributes role-based sub-goals to the overall goal and each participant must possess the SA needed to discharge their role (responsibilities) in relation to others' activities. The degree to which every team member possesses this SA is known as team situation awareness (TSA). The TSAthus 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.These conditionsresultnot only in the repetition of various activities but 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;Prassana et al., 2009).Several studies (O'Connor et al., 2008; Endlsey& Robertson, 2000; Endlsey& Rodgers, 1994) have also explained how a system fulfilling SA requirements can maintain the required level of SA and better support such decision-making.However, these studies tend to underestimate the criticalrole of SSA and TSA. At the same time, very little work has been done to see how SA, SSA, or TSA can be improved.This paper describes the design and development of a prototype computer system (SAVER) to improve SA, SSA, and TSA andits evaluationfor decision making and implementation during mass evacuation following a tsunami. Detailed information on the SAVER design and performance is available elsewhere (Javed et al., 2012). Here we provide an overview of the design framework and operation.

The study is carried out in New Zealand but extrapolates easily to other countries and emergency situations.

2 SAVER Design and Development

In Endsley'sseminal model of SA, an individual's SA requirements are defined as the dynamic information needs associated with the person's goals (Endsley et al., 2003; Wickens, 2008; Endsley, 2000). Hence, supporting their SA will mean providing them with the information they need to make correct decisions and carry out the tasks to achieve these goals(Albers, 2004).Endsley's model differentiates three levels; perception (Level 1), comprehension (Level 2) and projection (Level 3) at which relevant information should be provided.

The information requirements of different emergency roles needed to develop and maintain the SA forvarious phases of mass evacuation have been gathered and reported previously (Javed et al., 2011). These requirements are the basis of our system design. To provide specific and easily used information, SAVER considers the users' contextual parameters, i.e. their roles, responsibilities, goals and tasks and, more importantly, the information required to develop and maintain their SA to carry out these tasks. In effect, SAVER provides the right information to the right persons at the right time.This overall objective is attained by the semantic modelling of the contextual information (Chen et al., 2004).

2.1 Acquiring context specific information

Context information about the managers, their tasks, activities, and situational roles can be used to distinguish them from one another (Chen et al., 2004). Moreover, the same attributes can be used to provide the specific information they require. Hence, systems using the context information to provide services are called context-aware systems.

SAVER automates the processing ofcontext information (roles, current objectives, tasks and location etc)and combines them with SA requirements to fulfil the contextualised SA requirements. The system also uses contextual information for adaptive user interface and adaptive content generation. Figure 1 shows how various context parameters can be used to provide specific information to the users in a personalised form.

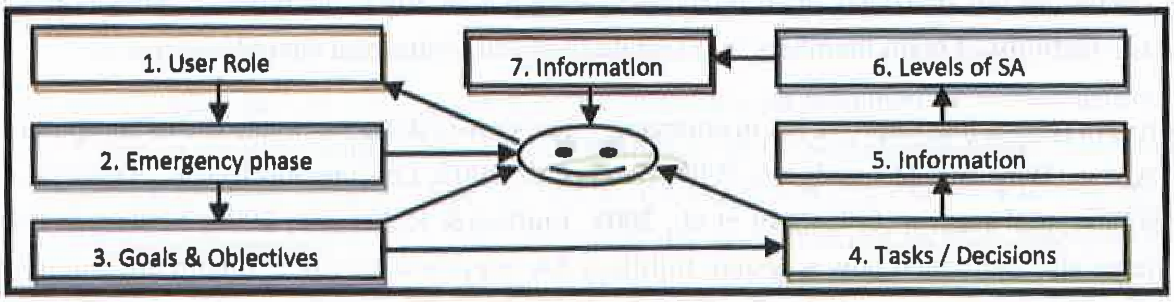

Figure 1: Selecting specific information for users using contextual information

Acquiring an accurate picture of context is a great challenge in context-aware systems. Our research uses ontology-based modelling and inferring of context information to provide personalised information to emergency managers.

2.2Contextual reasoning and ontology-based inference

Context reasoning is a method of processing the context information and making it usable in context-aware systems. Context reasoning also detects and resolves inconsistent information about the context. To enable automatic processing of context information it must be presented in machine processable form. Previous work (Schilit et al., 1994; Asthana et al., 1994; Dey, 2000) has presented contextual information using data structures or class objects in programming languages. However, since these languages only provide syntax representation they lack semantic representation and hence interoperability which is considered essential for information sharing (Chen et al., 2004).

Chen 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 formal language (machine processable) and also allows rule-based inference. Another important reason for choosing an ontology-based approach for context reasoning is that our research already uses ontology-based situation modelling (Javed et al., 2012). Therefore, both situation modelling and context 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 to add more dimensions of context information, e.g. types of devices (desktop computers, smart phones, personal digital assistants, computer tablets etc.), to provide personalised information according to the device features (Christopoulou and Kameas, 2005).

2.3Systema ofontology-based contextual SA

Figure 2 shows the architecture design of SAVER using ontological contextual and situation reasoning.

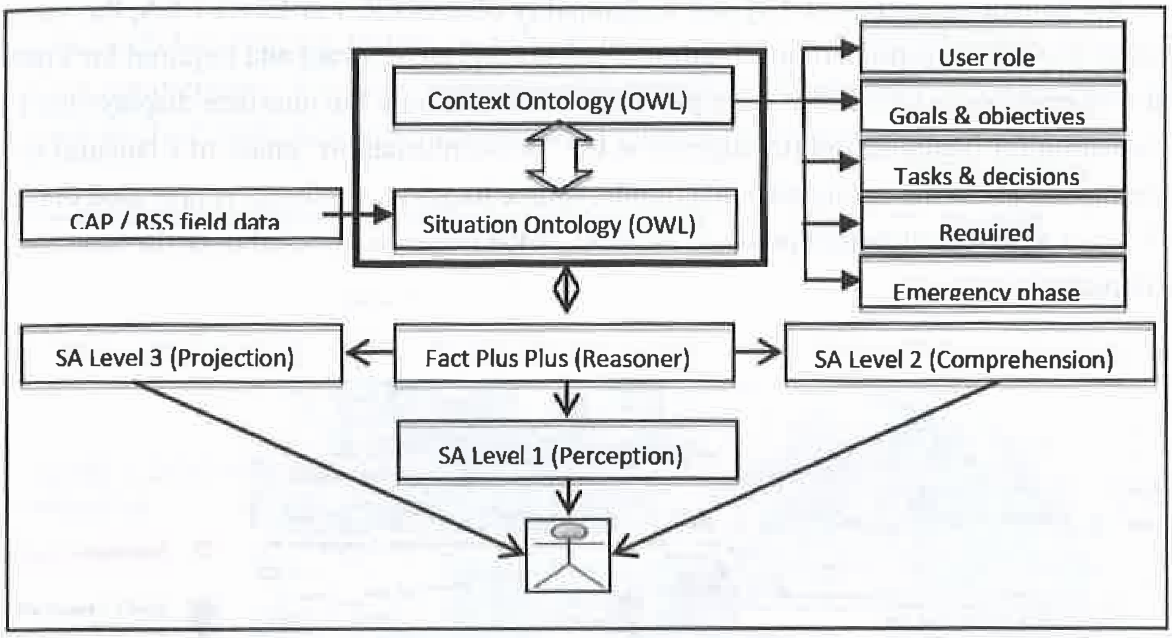

Figure 2: Architecture design of SAVER using contextual information

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, e.g. 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 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 a currentStatusand status can only be changed in sequence, i.e. from "pre-confirmation phase" to "tsunami confirmed decision phase" and so on.Hence, SAVER can support the SA of emergency managers by providing the personalised information required for developing the desired level of SA. Moreover, it improves SA by providinglevel 2 and3 SA information directly to update human SA (Salas et al., 1995).

To support the common understanding of the situation, which is called TSA by Salas et al.(1995), SAVER can provide the 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 confident that their understanding of the prevailing situation is correct and shared at both individual and team levels. 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 analyse the situationcritically.

The semantic modelling of the situation and user context can maximize the proactive sharing of information requirementsneeded to develop a common understanding of the situation. The semantics can also enable SAVER to identify and automatically share (with user consent) the information about a team member that is a requiredby another member.

2.4The SAVER interface

A prototype user interface of the SAVER system was developed to see if the information provided by SAVER improved the SA of emergency managers (Javed et al., 2011). The designwas also used to evaluate the human interaction (HCI) and functionality of SAVER. For Level 1 SA, the interface is designed to provide perception of information elements that are relevant and required for a particular job role and emergency phase. For example, Figure 3 shows how the interface displays the Level 1 SA information for Planning and Intelligence at the "pre-confirmation" phase of a tsunami scenario. The information about the earthquake magnitude, source location, depth etc. is provided to represent Level 1 SA at a pre-confirmation phase of tsunami, if the cursor is hovered over the icon indicating the earthquake.

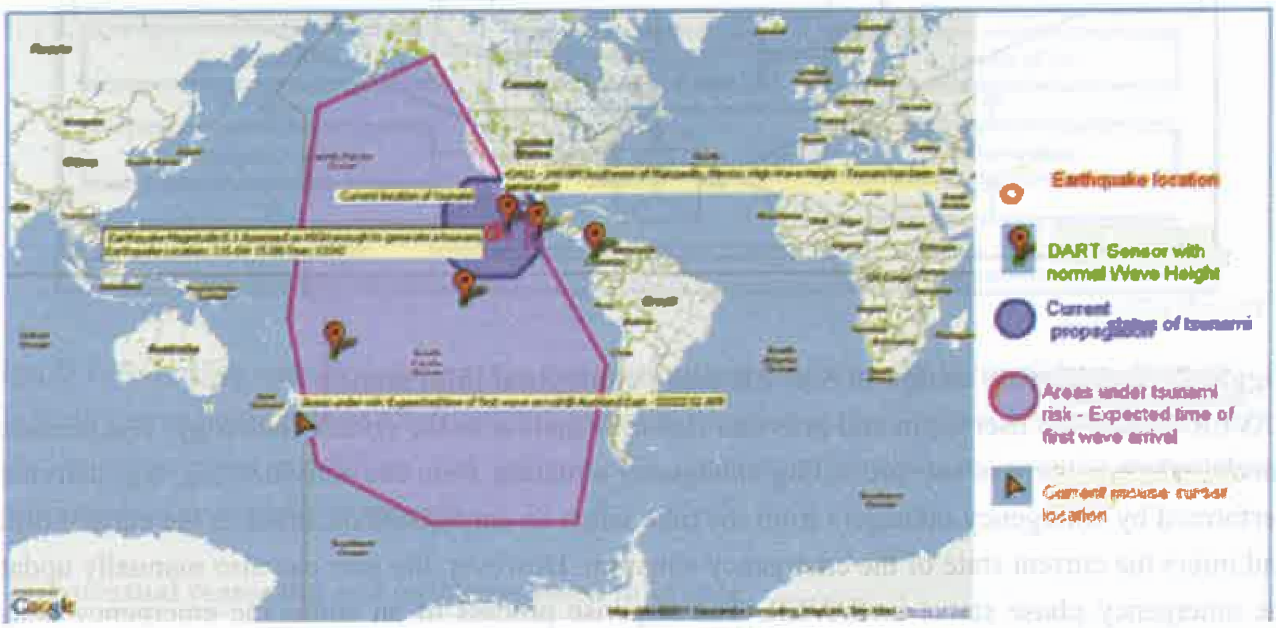

Figure 3: Providing comprehension and projection about the evolving situation

In Figure 3, a 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 or off shore.

Details of wave heights from Deep-Ocean Assessment and Reporting Tsunami (DART)data are provided in text format and the same wave attributes are displayed as a Level 1 SA if the cursor is placed on the sensor icon as shown in the figure. 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 normal using red, pink, blue and green colours respectively. Moving the cursor on these circles also displays a "tool tip" note that "wave height is HIGH" if the circle is pink. For Level 3 SA, the predicted time of arrival of the wave along with the expected height is provided to managers so that they can start preparations and planning for the probable evacuation while detailed inundation models are developed. This interpretation also explains the significance of perceived information in relation to the goals and objectives of a particular job role (user). Similarly, the blue circle in Figure 3with blue fill indicates the current position of propagating waves based on DART data.

Level 3 SA information is also provided in the form of a prediction about the future states of a situation. For example, in Figure 3, 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.

Another useful SA-enhancing feature of SAVER relies on its knowledge of emergency managers' information requirements. Knowing these requirements, SAVER automaticallyasks for the desired information on the behalf of person who needs it. Figure 4shows an example.

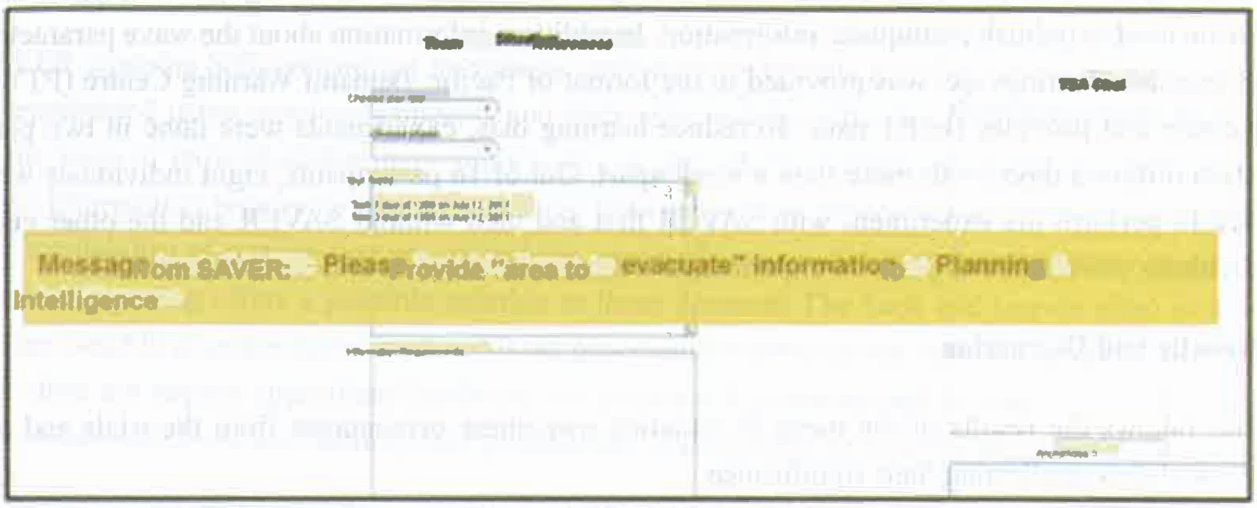

Figure 4: Example message from SAVER asking for information

Similarly, information about the relevant team member's SA is shared to improve common SA (TSA).

3 Evaluation

3.1 Direct measurement of SA, SSA and TSA

To evaluate the performance of our prototype design, SAVER we objectively measuredthe SA of emergency managers using, and without using, SAVER.Objective measures of SA have been extensively validated to be reliable for various domains (Fracker, 1998; Gugerty, 1997;Endsley and Rogers, 1998). Data are collected at various stages of a simulation scenario by freezing the simulation and asking the participants questions about the environment (Saner et al., 2009). The answers are then compared with the reality of the situation to determine the situation awareness as a percentage of correct answers. Questions are posed at an individual's perception (Level 1 SA), comprehension (Level 2 SA), and projection (Level 3 SA) levels of the situation.

A widely used and accepted SA measurement technique,Situation Awareness Global Assessment Technique (SAGAT) (Endsley, 2000) was used to gather data. This type of measurement directly taps into the operator's perception rather than inferring them from their behaviours, which may be affected by other factors (Endsley, 2000).

3.2Evaluation of SAVER

In our study, SAVER was evaluated using a simulation of a tsunami episode. The simulation experiments were undertaken by 16experienced emergency managers with up to 8 years practical experience, all of them havingpreviously participated in either a real event or in a national exercise. Individuals were required to complete a situation report about the prevailing situation. Information about the earthquake parameters, wave attributes like height, location etc. was 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 using the interfaces shown above. During the task, the session was frozen and a web-based application opened a question in front of the participant. Once, the participant has answered all the questions, they can continue with the task. Participants were asked directly about the situation, e.g., what is the location of earthquake source? In trials in which the participants were not using SAVER, they were provided with a document containing information in the format provided by the United States Geological Survey(USGS) website used to publish earthquake information. In addition, information about the wave parameters and tsunami warnings etc. was provided in the format of Pacific Tsunami Warning Centre (PTWC) website that provides DART data. To reduce learning bias, experiments were done in two parts on two different days, with more than a week apart. Out of 16 participants, eight individuals were asked to perform the experiment with SAVER first and then without SAVER and the other eight individuals were asked to perform experiments without SAVER first and then with SAVER.

4 Results and Discussion

Table 1shows the results of the mean % situation awareness percentages from the trials and the statistical data confirming their significance.

Table 1:Situation awareness percentagesof SA, SSA, and TSA measurements

Construct Measured	Mean % situation awareness using SAVER	Mean % situation awareness not using SAVER	t-value	p-Value
Individual SA	82.6	73.0	2.84	p = 0.008
Shared SA (SSA)	78.5	67.3	5.95	p< 0.001
Team SA (TSA)	81.9	59.5	4.50	p = 0.003
Combined SA (TSA)	91.8	83.4	4.42	p = 0.003

The results show that an individual's SA is improved by using SAVER during the experiments. It seems that the SAVER's SA-oriented design improves SA by providing individuals with the information they need to understand the situation. Moreover, by processing the information on their behalf, SAVER also supports their cognitive resources like short-term memory. Similarly, sharing the interpretation of the situation and prediction about the evolving situation successfully updated the individual's SA.

The full results (Javed et al., 2012) also show that SAVER not only improves the overall SSA of teams but also significantly improves the SSA at all three levels. It appears that SAVER's suggestions about the information requirements of team members to develop and maintain SA improvesthe SSA of the teams. Reminding them about their own and their team members' requirements reduces the need to remember the requirements and hence the cognitive workload and helps them to keep these requirements in mind.

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http://www.usgs.gov/
http://ptwc.weather.gov/

5 Implementation Requirements of SAVER

Whilst the architectural specification of SAVER is subject to revision based on the results of further research, it does provide proof of concept and offers a sound implementation strategy for ontology-based information systems to increase the operational effectiveness of emergency managers. The functioning and usefulness of SAVER have been demonstrated by the prototype but a considerable amount of work is needed to translate it intoreal environments.SAVER also needs to be tested with real data especially with large data sets.

SAVER contains both conceptual knowledge and instance knowledge. The conceptual knowledge is represented using ontology concepts and their relationships whereas the instance knowledge is in the form of individualidentifiers and situational data. With complex situations and large teams, these information requirements mandate huge storage and fast processing to guarantee the quality and availability of service that are critical for successful usage and trust by emergency managers. Cloud computing offers a possible solution to these demands.The back end (server side) is stored on the cloud in a secure environment. All the processing is done on the server side so that the client side does not require specialised hardware and software for running and storing large applications. A web-browser front end needing low processing capability can be used for access.

With this model, SAVER will become scalable in terms of storage space as well as the processing power it requires for processing large and complex ontologies. It can then be extended for many other types of disaster contexts, organizations and users.

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. The interface should provide a way to build semantically enriched queries to take full advantage of ontology-based systems. 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.

With the extensive improvement in the computing and graphical capabilities of mobile devices, these technologies are now perfect candidates to keep the users up to date with the prevailing situation anywhere, any time. Similarly, touch screens can reduce the amount of learning and effort required for information retrieval since maps and graphical components can be directly touched, dragged and dropped for input in a natural way. A combination of a graphical query interface with multi-touch screens would be an astonishing application of both technologies.

6 Conclusion

This paper describes the design and development of the SAVER system that aims to improve the SA, SSA and TSA of emergency managers in emergency situations. The evaluation of a prototype shows that SAVER does significantly support and improvethese forms of situation awareness at the perception, comprehension and projections levels. The use of such systems can enhance the effectiveness and efficiencyof decision-making and collaborative task performance.

7 References

Adams, M.J., Tenney, Y.J., Pew, R.W. (1995). Situation awareness and the cognitive management of complex systems. Human Factors, 37(1), 85-104.

Asthana, A., Cravatts, M. & Krzyzanowski, P. (1994). An indoor wireless system for personalized shopping assistance. In IEEE Workshop on Mobile Computing Systems and Applications, Santa Cruz, CA, US, 1994.

Bergstrand, F. & Landgren, J. (2009). Using live video for information sharing in emergency response work. International Journal of Emergency Management. Vol 6(3/4). Indersciences Enterprises Ltd.

Betts, B. J. (2005). Improving situational awareness for first responders via mobile computing. Moffett Field, Calif, National Aeronautics and Space Administration, Ames Research Center. http://purl.access.gpo.gov/GPO/LPS123514.

Bryant, D.J. (2002). Making naturalistic decision making 'Fast and Frugal'. In Proceedings of the 7th International Command and Control Research and Technology Symposium. Quebec City, ON, Canada, September 2002. Available at: http://pubs.drdc.gc.ca/PDFS/unc48/p523444.pdf.Accessed on April 2011.

Chen, H., Finnin, T. & Joshi, A. (2004). An ontology for context-aware pervasive computing environments. Special issue on ontologies for distributed systems. Knowledge Engineering Reviews. 18(3), 197 – 207.

Christopoulou, E., & Kameas, A. (2005). GAS Ontology: An ontology for collaboration among ubiquitous computing devices. International Journal of Human Computer Studies, 62(5), 664-685.

O'Connor, P., Campbell, J., Newon, J., Melton, J., Salas, E., & Wilson, K. (2008). Crew resource management training effectiveness: A meta-analysis and some critical needs. International Journal of Aviation Psychology, 18(4), 353-368.

Dey, A. K. (2000). Providing Architectural Support for Building Context-Aware Applications. PhD thesis, Georgia Institute of Technology, 2000.

Endsley, M. R.& Robertson, M. M. (2000).Situation awareness in in aircraft maintenance teams. International Journal of Industrial Ergonomics,26, 301-325.

Endsley, M. R. & Rodgers, M. (1994). Situation awareness information requirements for en route air traffic control. Washington, D.C: U.S. Dept. of Transportation, Federal Aviation Administration, Office of Aviation Medicine.

Endsley,M.R.& Jones,W.M.(2001).Amodelofinter-andintra-teamsituation awareness:Implicationsfordesign,trainingandmeasurement.InNewTrendsin CooperativeActivities:UnderstandingSystemDynamicsinComplexEnvironments, M. McNeese, E. Salas and M. R. Endsley (Eds.), Santa Monica, CA: Human Factors and Ergonomics Society.

Endsley, M. R. & Rodgers, M. (1998). Distribution of attention, situation awareness, and workload in a passive air traffic control task: Implications for operational errors and automation. Air Traffic Control Quarterly 6(1), 21-44.

Endsley, M.R., Bolte, B.& Jones, D.G. (2003). Designing for Situation Awareness: An Approach to Human Centred Design. London: Taylor & Francis.

Endsley, M.R. (1995). Toward a theory of situation awareness. Human Factors, 37(1), 32-64.

Endsley, M. R. (2000). Theoretical underpinnings of situation awareness: A critical review, In M. R. Endsley & D. J. Garland, (Eds). Situation Awareness Analysis and Measurement. Mahwah, NJL Lawrence Erlbaum Associates Inc., pp. 3-32.

Fracker, M. (1998). A theory of situation assessment: implications for measuring situation awareness. In Proceedings of Human Factors Society. 32nd Annual Meeting. pp. 102-106.

Gugerty, L. & Tirre, W. (1997). Situation awareness: a validation study and investigation of individual differences. Proceedings of Human Factors and Ergonomics Society. 40th Annual Meeting. pp. 564-568.

Javed Y & Norris T, Prototyping and evaluation of a computerized emergency management system based on an ontological inference design, Proceedings of the IEEE Conference on Global Humanitarian Technology Conference (GHTC): Seattle, October 2011, pp 462-466.

Javed, Y., Norris, T., Johnston, D. M.& Doyle, E. H. (2011). Towards a framework for crisis decision support systems: Information requirements for contextual team situation awareness. In CutterIT Journal: Special Issue on IT and Crisis Management, Vol 24, Issue 1. pp 26-33.

Javed, Y., Norris, T. & Johnston, D. M. (2012). Evaluating SAVER: Measuring shared and team situation awareness of emergency decision makers. 9th International Conference on Information Systems for Crisis Response and Management (ISCRAM 2012), Vancouver, Canada. pp. 1-11.

Klein, G. (2000). Analysis of situation awareness from dritical incident report. InM. R. Endsley & D. J. Garland, (Eds.) Situation Awareness Analsysis and Measurement. Mahwa, NJ: LawrenceErlbaum Associates Inc., pp 51-72.

Lanfranchi, V. & Ireson, N. (2009). User requirements for collective intelligence emergency response system. In Proceedings of the 2009 British Computer Society Conference on Human Computer Interaction. Cambridge, United Kingdom, 1-5 Sept, 2009, pp. 198-203.

Prasanna, R., Yang, L. & King, M. (2009). GDIA: A cognitive task analysis protocol to capture the information requirements of emergency first responders. In Proceedings of the 6th International ISCRAM Conference. Gothenburg, Sweden, 10-13 May 2009.Resnick, 2003.

Salas, E., Prince, C., Baker, D. P. & Shrestha, L. (1995). Situational awareness in team performance: implications for measurement and training. Human Factors 37, 123–136.

Saner, L.D., Bolstad, C.A.,Gonzales, C.& Cuevas, H.M., (2009). Measuring and predicting shared situation awareness in teams., Journal of Cognitive Engineering and Decision Making, 3(3), 280-308.

Schilit, B. N., Adams, N., & Want, R. (1994). Context-aware computing applications. Palo Alto, Calif: Xerox Corp., Palo Alto Research Center.

Shu, Y. & Furuta, K., (2005). An inference method of team situation awareness based on mutual awareness. Cognition Technology & Work, 7, 272–287.

Smith, K. & Hancock, P.A. (1995). Situation awareness is adaptive, externally directed consciousness. Human Factors, 37(1), 137-148.

Wickens, C. D. (2008). Situation awareness: Review of Mica Endsley's 1995 articles on SA theory and measurement. Human Factors, 50(3), 397-403.