SITUATION AWARENESS APPROACH TO CONSTRUCTION SAFETY MANAGEMENT IMPROVEMENT

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Situation Awareness (SA) improves decision-making and performance in complex, dynamic environments by enhancing ambient awareness of the system-user. Until now, SA has not been considered as a potential method of improving job-site safety in construction. The purpose of this study is to provide a conceptual model of situation awareness approach to construction safety management. Developing construction management methods and support systems that centre on SA requirements can improve safety managers' decision-making processes. This study applies the Goal Directed Cognitive Task Analysis (GDTA) technique to obtain the Construction Safety Manager's information requirements. These SA requirements lay the foundation for future role-based decision support systems that will assist construction personnel in decision making in dynamic environments such as the construction job-site.

Keywords: construction safety, decision making, human factors, situation awareness.

INTRODUCTION

Worker safety is one of the most important concerns within the construction industry. Since the construction jobsite is a complex environment with a large amount of information to keep up with, safety managers should be capable enough to build an accurate mental picture of safety practices on the jobsite and make sure they are correctly implemented (Endsley, Bolte, and Jones 2003). For clarifying this mental picture, safety managers should have a clear understanding of what their goals, decisions, and information requirements are. This clarification gives birth to the concept of Situation Awareness (SA), which has the potential to be applied in the construction environment and to provide safety managers with the said mental picture. For designing a system that supports SA, interviews were conducted with professionals in the field of construction safety. These professionals are referred to as Subject Matter Experts (SMEs) due to their professional background, experience and expertise in the area of construction safety. By following the methodology of Goal Directed Cognitive Task Analysis (GDTA), a hierarchy of goals, decisions and related information requirements was developed. This hierarchical SA graph has the potential to be the basis for the development framework of a human-computer interface that can be used on computers or Personal Digital Assistants (PDAs) to help the safety managers access appropriate information anytime anywhere.

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BACKGROUND OF RESEARCH

Safety in construction industry

In 2005, Construction produced 4.9% of the total Gross Domestic Product (GDP) in the USA (CPWR 2007). One of the main concerns in such a financially important industry is related to safety issues. Technological advances in personal protective equipment have improved the safety of workers. However, even with such improvements, construction continues to be one of the most dangerous industries in the U.S. economy (Irizarry and Abraham 2005). In 2005, the construction death rate in the United States was relatively high, 10.5 per 100,000 workers, and the losses due to the death of a construction worker valued at $4 million, while a nonfatal injury involving days away from work costs approximately $42,000 (CPWR 2007). Construction workers are still prone to accidents that lead to material losses, to temporary or permanent disabilities, and to fatalities. Some of the incidents leading to building construction fatalities are due to collisions between workers and equipment, or workers falling from roofs, scaffolds or trench edges. Accident prevention has been addressed by both researchers and practitioners. One of the ways to prevent accidents is to provide the safety managers on job sites with a correct and accurate mental picture of safety environment on their jobsites. Applying the concept of Situation Awareness within the safety management of construction practices can help safety managers in the development of that mental picture.

Overview of SA

SA is having awareness about what is happening around, in order to make decisions based on that information, now and in the future. SA clarifies what is needful for reaching the goals of a specific job by understanding what important information is to be used in the decision-making process. Formally, SA has been defined by Endsley (1988, 1995, and 2000) as “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future”. In other words, the formal definition of SA is categorized into three hierarchical phases: Perception of elements in current situation; Comprehension of current situation; Projection of future status. In the case of losing situation awareness, individuals are usually slower in finding problems within the system and they would need additional time to diagnose the problem and apply remedies to fix them (Endsley and Kiris 1995). As even small lapses in situation awareness may cause serious problems, different manner of application domains have started to embed this concept in their potential realms (Endsley 1995). The first usage of situation awareness term is within military aviation, where the pilot should achieve high level of situation awareness due to critical and challenging potential of military aviation (Endsley, Bolte, and Jones 2003). In lots of other domains SA plays a very important role as a foundation for decision-making and performance. Various areas such as fighter aircrafts, electronic systems and automation technology, weather forecasting, driving and ground transportation, energy production and distribution, space operations, and medicine are applying the SA methodology (Endsley 2000). The Architectural, Engineering, and Construction (AEC) domain has not applied this methodology in spite the clear parallels to many goal driven domains. This study takes the initial steps in the application of Situation Awareness to the AEC domain.

For designing a system, which supports SA, the operator must identify and illuminate the individuals’ needs/tasks in the team, their interaction with one another to meet the common goals, and their information needs to perform the tasks. In this research a form of cognitive task analysis, the goal directed cognitive task analysis (GDTA), has

been used for this purpose (Bostald, Riley, Jones, and Endsley 2002). GDTA has been employed broadly for analyzing SA requirements of individuals (Endsley 1993; Endsley and Rodgers 1995). Some important reasons that GDTA was selected are (1) it is not tied to the technology being used to carry out the task (i.e., it is independent of how tasks are done within a given system but it depends to what information is needed); (2) it does not just focus on people's data need, but on how the said data can be used within decision making and goal attainment process; and (3) it focus on obtaining an accurate depiction of the SA requirements and key goals for each individual (Strater, Endsley, Pleban, and Mathews 2001; Bostald *et al.* 2002).

Applying SA to construction safety management

Due to the complex environment of construction jobsites, safety managers cannot easily filter and organize information in an accurate manner. This results in less than optimal decisions being made.

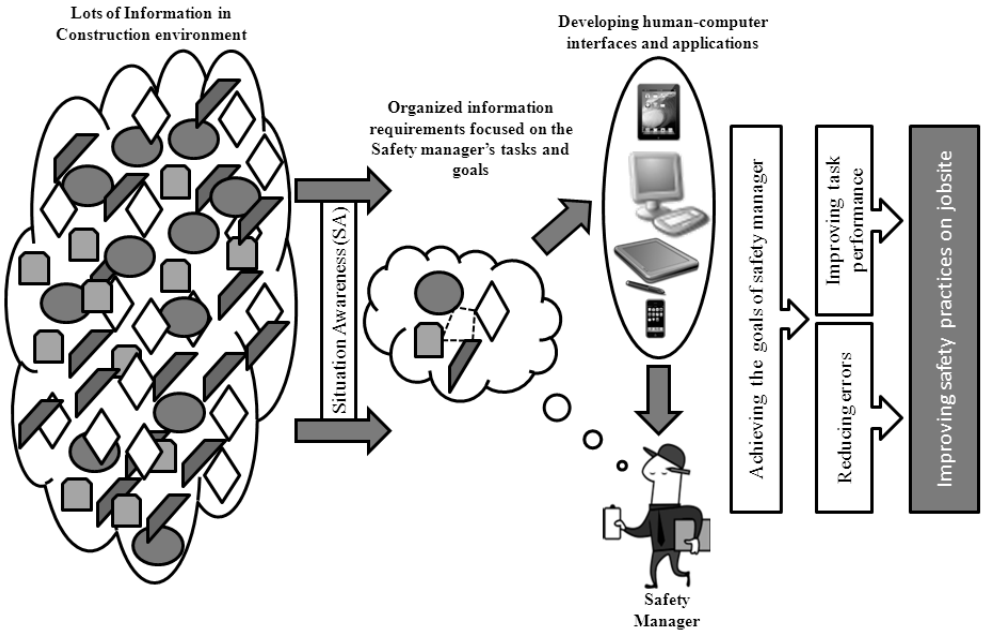

Figure 1 The conceptual model of construction safety and SA integration

Figure 1 illustrates a conceptual model that can help safety managers to overcome the complexity of provided information on jobsites. SA can filter the large amount of information on jobsites and provide the safety manager with organized and required information. The organized information requirements not only can shape the mental picture of the safety manager but also have the potential to be used as a basis for developing human-computer interfaces and applications. The improved mental picture together with human-computer interfaces can improve the decision making process of safety managers to achieve their goals on construction jobsite. The goals such as reducing errors and improving the task performance can lead to improving safety practices on the jobsite. Application of this method is not intended to provide a one-size-fits-all solution to safety issue on construction jobsite. Its purpose is to increase SA and assist safety management by enhancing access to information relevant to good safety performance. It is the safety manager that is ultimately responsible for the final analysis of the available information and the corresponded course of action. Although this method may assist in measuring what is measurable in terms of data, the safety manager should be vigilant of other factors such as human behaviour.

METHODOLOGY

Goal Directed cognitive task analysis (GDTA) technique

GDTA is a cognitive task analysis and has three main components: goals, decisions, and SA requirements (Endsley *et al.* 2003). GDTA focuses on (1) the basic goals of the operators (2) the major decisions for accomplishing these goals, and (3) the SA requirements for each decision. The knowledge provided by GDTA can help designers to design systems with better situation awareness, which leads to better decision-making and process performance. The steps involved in the GDTA interview are as follows (Endsley *et al.* 2003).

1. Identification of key decision makers.
2. Identification of major goals and associated sub-goals for each decision maker.
3. Identification of the primary decision needed for each sub-goal.
4. Identification of the SA information requirements for making those decisions and performing each sub-goal.

The information obtained from the GDTA is organized into charts depicting a hierarchy of the three main components of GDTA (i.e., goals/subgoals, decisions relevant to each subgoal, and the associated SA requirements for each decision). The output is used to assist the safety managers to have better safety performances.

Method

Application of the GDTA involved interviews in which the interviewer asked each subject about his/her main goal as a safety manager at job site. Then the interview continued to find out the sub goals, which are necessary to accomplish the main goal. These sub goals would serve to set the direction of the remainder of the interview and clarifying the information needs to accomplish the sub goals of a construction safety manager. At the end of the interview, subjects were asked to indicate if there were any type of technology that would help them to accomplish those goals, and what would this technology be. Six safety managers (SMEs) in the Atlanta, Georgia area participated in the GDTA. One-on-one interviews were conducted with those safety managers following the GDTA methodology. The interviews lasted approximately one hour and were video recorded for the purpose of reviewing responses. Subjects provided their consent before the interviews and the study protocol was reviewed and approved by the Georgia Tech Institutional Review Board for compliance with Human Research Subjects regulations. Based on these interviews, goal hierarchies were developed with related SA requirements. By combining these hierarchies, a unique hierarchy of goals for the safety managers in the construction industry was achieved.

RESULTS

The main goal of a safety manager was identified as “providing a safe workplace for parties in construction to reduce accidents, injuries, and hazards on jobsite.” The following graph illustrates the hierarchy of main goal and sub goals of job-site safety management.

As illustrated in Figure 2, for achieving this main goal, safety managers should accomplish three major subgoals. These three subgoals are (1) performing inspections for hazards on jobsite, (2) providing training for parties working on jobsite, and (3) managing accidents.

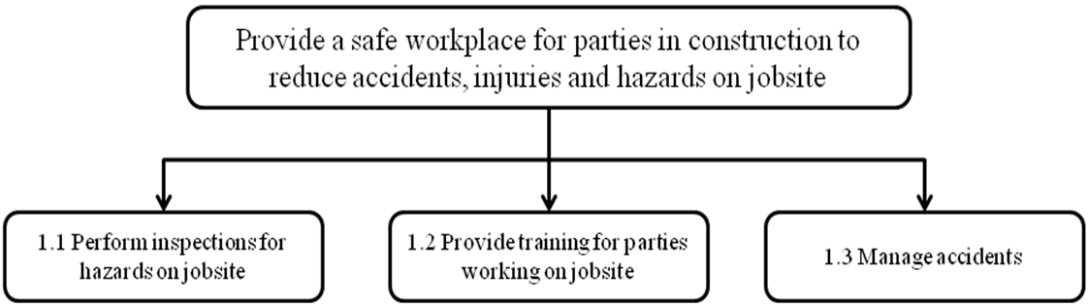

Figure 2: Goal hierarchy of safety managers

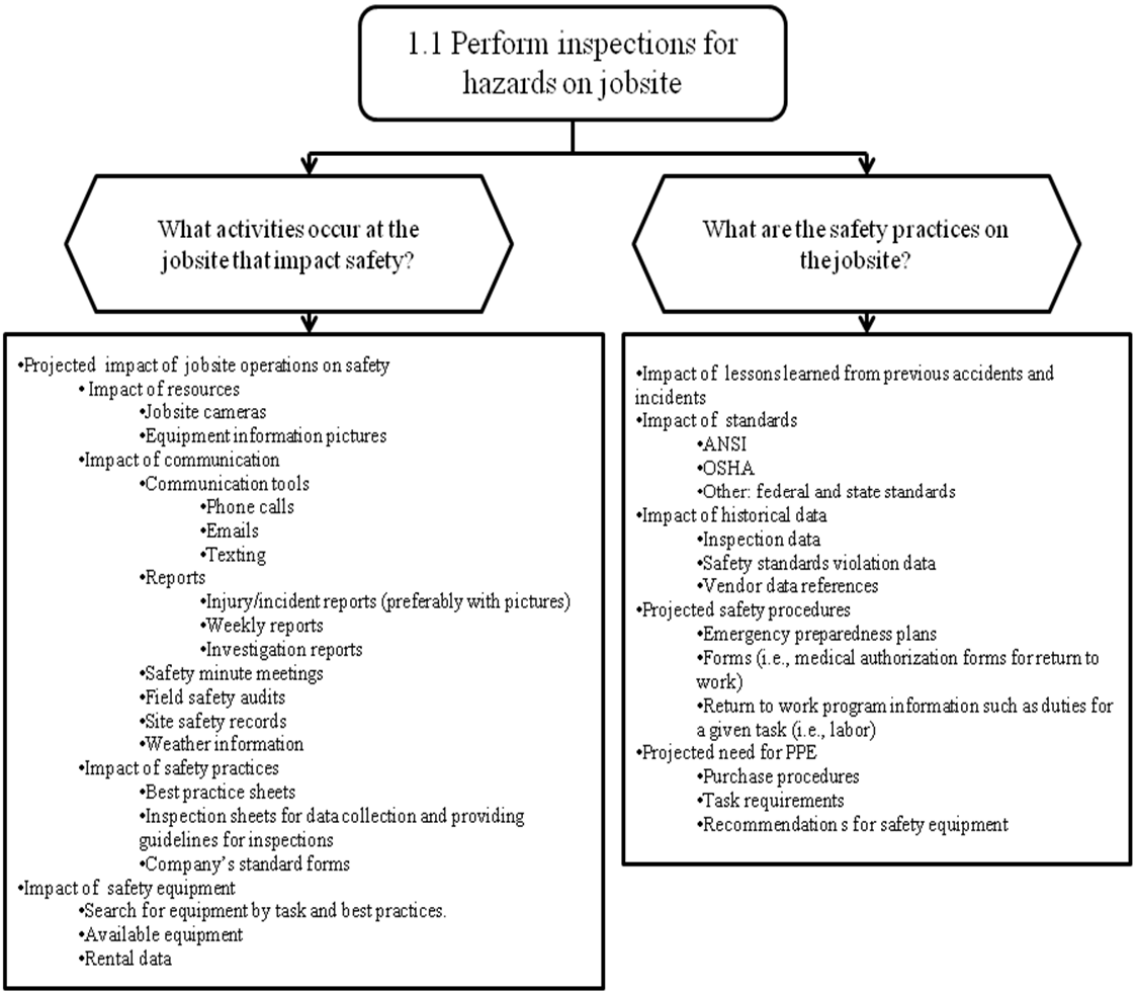

Figure 3: Decisions and SA requirements for first subgoal of safety managers

"Performing inspections for hazards on jobsite" is the first subgoal, which was declared by SMEs for accomplishing the main goal of a safety manager. Based on the Figure 3, for achieving this subgoal, safety managers should answer two questions.

1. What activities occur on jobsite that impact safety.
2. What are the safety practices on jobsite.

These questions show the decisions that safety managers should make to accomplish "inspection for hazards on jobsite" (first subgoal). The bullet points in the graph are the information and SA requirements that a safety manager needs in order to make these decisions. For knowing what activities occur on jobsite that impact safety, safety managers should for example consider the impact of resources by using or equipment information/pictures. Or for making the second decision about what the safety

practices are on jobsites, SMEs recommended that safety managers should for example get requirements such as lessons learned from previous accidents and incidents; access to various standards (The American National Standards Institute (ANSI), The Occupational Safety and Health Act (OSHA), and United States federal and state level standards); inspection/violation data; and emergency preparedness plans.

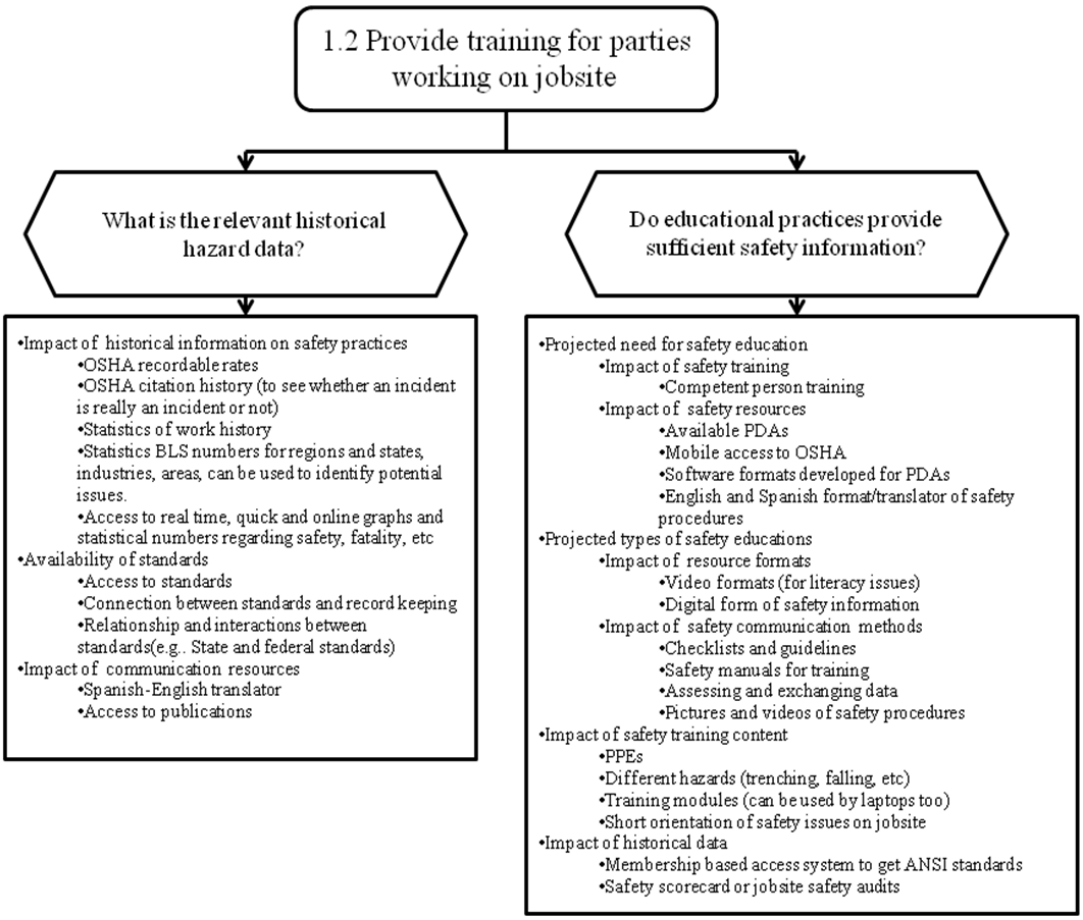

Figure 4: Decisions and SA requirements for second subgoal of safety managers

SMEs declared "providing training for parties working on jobsite" as the second subgoal for accomplishing the main goal of a safety manager. Figure 4 Shows for achieving this subgoal safety manager should answer two different questions.

1. What is the relevant historical hazard data.
2. Do educational practices provide sufficient safety practices.

These questions show the decisions that safety managers should make to accomplish the second subgoal (providing training for parties working on jobsite). Same as before, the bullet points in Figure 4 are the information and SA requirements that a safety manager needs in order to make these decisions. For example, for finding out the relevant historical hazards data on jobsite, the safety managers should go through information and requirements such as OSHA recordable rates and citation history; having access to different safety standards and their relations/interactions; and different statistical data of injuries/hazards on the jobsite. Or for making the second decision about educational practices on jobsites, SMEs recommended that safety managers should be provided with requirements or information such as safety training and resources with different contents and formats which can be installed and used by different communication methods/tools.

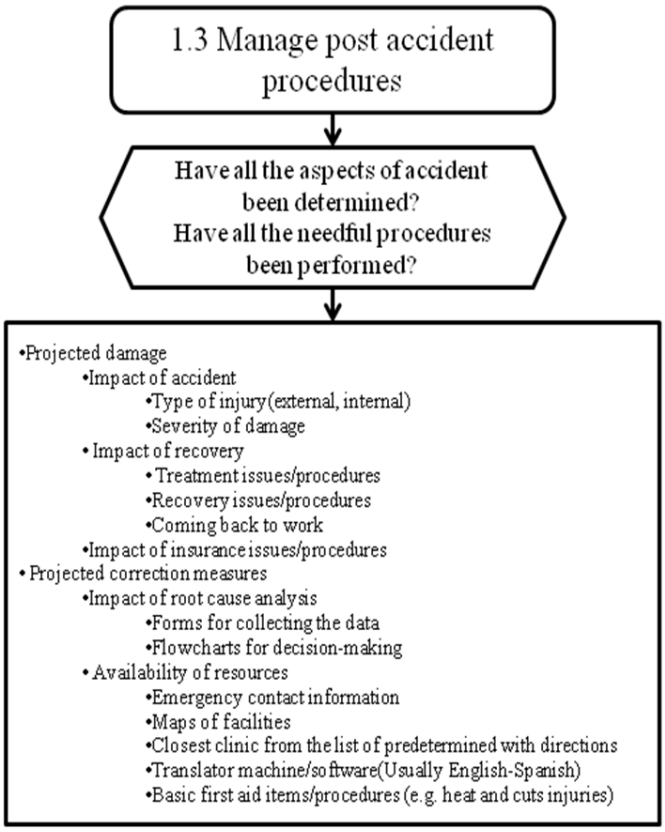

Figure 5: Decisions and SA requirements for third subgoal of safety managers

SMEs declared "managing accidents" as the third subgoal, for accomplishing the main goal of a safety manager. Figure 5 shows that for achieving this subgoal, safety managers should answer questions such as "Have all the aspects of the accident been determined?" or "have all the needful procedures been performed?".

These questions show the decisions that safety managers should make to accomplish the third subgoal (managing accident after it happens). The bullet points in Figure 5 are the information and SA requirements which a safety manager needs in order to make these decisions. This means that for making decisions related to determining different aspects of accidents and performing needful procedures, the safety managers should get requirements and information such as determining type and severity of accidents, and treatment/recovery from them; insurance issues; root cause analysis for determining correction measures; and different forms for collecting data.

CONCLUSIONS

The identified hierarchies have the potential to enhance ambient awareness of safety managers in the complex, dynamic environment of construction jobsites. Safety managers would make more accurate decisions by having previous knowledge of what could be their key goals and SA requirements. This technique has great potential of improving safety management practices on jobsites by identifying critical information and requirements for decision-making. This SA hierarchy can be improved in a way to embed more detailed goals and information and even be applied in other areas of the construction industry. In addition, the SA hierarchy can be used as basis for the development framework of a human-computer interface, which can be installed on computers and PDAs to be used by safety managers as a tool for decision-making in safety management practices on jobsites.

One of the main challenges of applying GDTA is that SA may vary from individual to individual. This limitation leads to a situation where each individual's SA goals or requirements may not be compatible to another. This difference can occur due to issues such as interviewee's background, experience, or specific role at work. To overcome this limitation, the interviews should be conducted in a way that involves various experts or more experienced interviewees from safety management domain. As another challenge in applying GDTA, Ensley *et al.* (2003) have mentioned, "not all interviews will go smoothly and result in optimal data collection." They believe that this challenge is mostly related to interviewee's personality factor that sometimes negatively influences the interview. In addition to interviewer's skills of leading the interview in the required manner, issues such as controlling for interviewee experience and pre-briefing them about the output of previous GDTA-based interviews, can be useful to overcome this challenge. Additional studies should be conducted to assess the validity of the GDTA method in finding the most relevant information for an enhanced SA of safety management personnel.

REFERENCES

Bolstad C A, Riley J M, Jones D G, and Endsley M R (2002) Using goal directed task analysis with army brigade officer teams. Paper Presented at the *Human Factors and Ergonomics* Society 47th Annual Meeting September 30th – October 4th, 2002, Baltimore, MD.

CPWR (2007) *The Construction Chart Book: The U.S. Construction Industry and its Workers*. The Centre to Protect Workers' Rights, Silver Spring, MD.

Endsley, M R (1988) Design and evaluation for situation awareness enhancement, *In Proceedings of the Human Factors Society 32nd Annual Meeting*, Santa Monica, CA: Human Factors Society, 97-101.

Endsley, M R (1993) A survey of situation awareness requirements in air-to-air combat fighters. *International Journal of Aviation Psychology*, **3**(2), 157- 168.SA Technologies, Inc. Marietta, GA.

Endsley, M R (1995b) Toward a theory of situation awareness in dynamic systems. *Human Factors*, **37**, 32-64.

Endsley, M R (2000) *Theoretical underpinnings of situation awareness: A critical review*. In M. R. Endsley and D. J. Garland (Eds.), Situation awareness analysis and measurement. Mahwah, NJ: LEA.

Endsley, M R and Kiris, E O (1995) The out-of-the-loop performance problem and level of control in automation. *Human Factors*, **37**, 381-394.

Endsley, M R and Rodgers, M D (1994) Situation awareness information requirements for en route air traffic control. *Proceedings of the Human Factors and Ergonomics Society 38th Annual Meeting*, (pp. 71-75). Human Factors and Ergonomics Society: Santa Monica, CA. 2 Methodology.

Endsley, M R, Bolte, B, and Jones, D G (2003) *Designing for Situation Awareness: An approach to human-centred design*. London: Taylor and Francis.

Irizarry, J and Abraham, D M (2005) Application of Virtual Reality Technology for the Improvement of Safety in the Steel Erection Process. *ASCE International Conference on Computing in Civil Engineering*, Cancun, Mexico, July 2005 (in print).

Strater, L D, Endsley, M R, Pleban, R J, and Matthews, M D (2001) *Measures of platoon leader situation awareness in virtual decision making exercises (Research Report 1770)*. Alexandria, VA: Army Research Institute.