CAE Professional Services (Canada) Inc.

1135 Innovation Dr.
Ottawa, Ont., K2K 3G7 Canada
Telephone: 613-247-0342
Fax: 613-271-0963

SITUATION AWARENESS: ANNOTATED BIBLIOGRAPHY

CONTRACT #: W7711-088140/001/TOR

FOR

MATTHEW DUNCAN

1133 Sheppard Ave. West, Toronto, Ontario, M3M 3B9

26 March 2012

Document No. DRDC CR 2012-115

CAE PS Document No. 5035-002 Version 01

APPROVAL SHEET

Document No. CAE PS Document No. DRDC CR 2012-115
5035-002 Version 01

Document Name: Situation Awareness:
Annotated Bibliography

Primary Author

002 5035-002 5035-002
002 5035-002 5035-002
002 5035-002 5035-002
002 5035-002 5035-002
002 5035-002 5035-002
002 5035-002 5035-002

Name	**Jaff Guo**	**Date**
Position	Consultant	

Reviewer

02 5035-002 5035-002
02 5035-002 5035-002
02 5035-002 5035-002
02 5035-002 5035-002
02 5035-002 5035-002
02 5035-002 5035-002

Name	**Tab Lamoureux**	**Date**
Position	Senior Consultant	

Approval

02 5035-002 5035-002
02 5035-002 5035-002
02 5035-002 5035-002
02 5035-002 5035-002
02 5035-002 5035-002
02 5035-002 5035-002

Name	**Kelly Forbes**	**Date**
Position	Human-Systems Integration Lead	

REVISION HISTORY

Revision	Reason for Change	Origin Date
Version 01	Initial document issued	16th March 2012

TABLE OF CONTENTS

LIST OF TABLES

ABSTRACT

A review of the theoretical literature concerning Situation Awareness (SA) was undertaken, covering the following six theme groups; SA and Cognitive Processes; SA Theories/Conceptual Models; SA Perspectives/Approaches; Team/Shared SA; SA Measures; and, SA Training. A total of 58 papers were reviewed for this contract. For each paper a summary is provided along with the bibliographic details in American Psychology Association (APA) format. This review will assist Defence Research and Development Canada (DRDC) to focus their efforts to support the Primary Leadership Qualification (PLQ) curriculum by highlighting the important and informative papers on SA.

RÉSUMÉ

Une analyse de la documentation théorique portant sur la connaissance de la situation (CS) a été entreprise, et portait sur les six thèmes suivants : la CS et les processus cognitifs; les théories et les modèles conceptuels relatifs à la CS; les perspectives et les approches liées à la CS; la CS en équipe ou partagée; les mesures de la CS, et la formation en matière de CS. En tout, 58 documents ont été analysés dans le cadre de ce contrat. Pour chacun d'eux, un sommaire est fourni ainsi que les détails bibliographiques sous le format prévu par l'American Psychology Association (APA). La présente analyse aidera Recherche et développement pour la défense Canada (RDDC) à axer ses efforts sur le soutien à apporter au programme de Qualification élémentaire en leadership (QUEL), en soulignant les documents importants et informatifs sur la CS.

EXECUTIVE SUMMARY

A review of the theoretical literature concerning Situation Awareness (SA) was undertaken, covering the following six theme groups:

- SA and Cognitive Processes;
- SA Theories/Conceptual Models;
- SA Perspectives/Approaches;
- Team/Shared SA;
- SA Measures; and,
- SA Training.

A total of 58 papers were reviewed for this contract. For each paper a summary is provided along with the bibliographic details in American Psychology Association (APA) format. This review will assist Defence Research and Development Canada (DRDC) to focus their efforts to support the Primary Leadership Qualification (PLQ) curriculum by highlighting the important and informative papers on SA.

SOMMAIRE

Une analyse de la documentation théorique portant sur la connaissance de la situation (CS) a été entreprise, et couvrait les six thèmes suivants :

- La CS et les processus cognitifs;
- Les théories et les modèles conceptuels relatifs à la CS;
- Les perspectives et les approches liées à la CS;
- La CS en équipe ou partagée;
- Les mesures de la CS;
- La formation en matière de CS.

En tout, 58 documents ont été analysés dans le cadre de ce contrat. Pour chacun d'eux, un sommaire est fourni ainsi que les détails bibliographiques sous le format prévu par l'American Psychology Association (APA). La présente analyse aidera Recherche et développement pour la défense Canada (RDDC) à axer ses efforts sur le soutien à apporter au programme de Qualification élémentaire en leadership (QUEL), en soulignant les documents importants et informatifs sur la CS.

1 INTRODUCTION

Defence Research and Development Canada (DRDC) – Toronto is supporting the Canadian Forces (CF) by providing learning content to support the Primary Leadership Qualification (PLQ). This training is undertaken by most members of the CF, and is required by members who lead small teams and those who lead larger groups. Increasing recognition of the relevance of Situation Awareness (SA) in arguably all activity has led to the desire to include specific training in SA for the ultimate benefit of members in command positions throughout the CF.

This task was funded under contract W7711-018840/TOR/001 “Research Support to DRDC Toronto Adversarial Intent Section”. The contract Technical Authority (TA) was Matthew Duncan.

1.1 Background

1.1.1 Situation Awareness

The term “Situation Awareness” was coined by Endsley (1988). There continues to be debate regarding whether SA is a process, a product, or both, what the components of SA are, how to train SA, and the role of cognitive processes in SA. However, the most widely used theory of SA continues to be Endsley’s (1988, 1995c):

SA is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and a projection of their status in the near future.

Three levels of SA have been described:

Level 1 SA: perception of the elements in the environment;

Level 2 SA: comprehension of the current situation; and,

Level 3 SA: prediction of future status.

1.1.2 The Primary Leadership Qualification

The PLQ exists to prepare CF members for command positions. Anecdotally, during the PLQ trainees were observed to be deficient with respect to giving orders, giving correct orders, or giving timely orders. It was concluded that these trainees lacked the SA required to effectively command others and give orders. A perceived emphasis on classroom instruction (versus operational or live simulation experience) was surmised to have led to a lack of experience in applying theory which meant that a trainee’s SA for command activities was under-developed.

The Team's Applied Research Project (ARP) was asked to develop training approaches to improve PLQ trainees' abilities to give orders. This work has identified increased use of virtual simulation as an important method of increasing trainees' opportunities to gain command experience. This work has also identified SA as a key enabling concept for successful PLQ candidates and, ultimately, for commanders at all levels of the CF hierarchy.

1.2 Objective

The TA's objective of this task is to compile an annotated bibliography of literature concerning SA under the following theme groups:

- Cognitive Processes;
- Theories/Conceptual Models;
- Perspectives/Approaches;
- Team/Shared SA;
- Measures of SA; and,
- Training of SA.

The literature to be compiled was to address a fundamental, generalizable concept of SA that is independent of a specific real-world context. At least five documents were to be reviewed for each theme group. The annotated bibliography was to be provided in Endnote format to the TA, along with electronic copies of all the documents reviewed.

1.3 This Document

This document has four main sections:

1. Introduction: This section, outlining the background and objectives of the work and discussing the organization of this report.
2. Method: Outlining the manner in which the search and selection of literature was undertaken and how the documents were summarized.
3. Annotated Bibliography: Divided into theme groups, each document selected is presented with its bibliographic details and a summary, with particular emphasis on its relevance to the theme group.
4. Conclusions: Although no synthesis of the literature was attempted, short conclusions were made regarding the volume of literature that exists for each theme group and the adequacy of the information that was reported.

5. References: The full list of references is presented in an alphabetical list for ease of consideration.

2 METHOD

For the purposes of this task two methods of searching for, and selecting, literature were followed: conventional keyword search and Subject Matter Expert (SME) direction. Conventional keyword search involved combining the primary and secondary terms in all possible combinations and entering the resulting combinations into Google Scholar (http://scholar.google.ca/schhp?hl=en). The primary and secondary terms are listed in Table 2-1 and correspond to Situation/Situational Awareness with the theme group headings.

Table 2-1: SA Annotated Bibliography Search Terms

Primary Search Terms	Secondary Search Terms
Situation Awareness Situational Awareness	Cognitive Processes Theories/Conceptual Models Perspectives/Approaches Team/Shared SA Measures of SA Training of SA

The paper titles and abstracts that were returned through the keyword search were considered for their relevance to the theme groups and the degree to which they spoke to the underlying theory of SA versus a specific domain application of SA. Selected papers were added to a Mendeley group (Mendeley is a bibliographic application that permits sharing of papers and comments). There was no timeframe for acceptable papers.

SME direction was also used to assist in the selection of papers found through conventional search. The SME (Dr Sébastien Tremblay of Université de Laval) has published extensively regarding SA and is the co-author of a book on the subject (A Cognitive Approach to Situation Awareness: Theory and Application; Banbury and Tremblay, 2004). The SME directed the team to obtain certain literature that represented the most valuable approach with which to address the theme groups. The SME also reviewed the papers being uncovered during the conventional search and recommended their inclusion or exclusion in the review. Since it would be expected that the conventional search and selection of papers would overlap with the SME's own contribution, the two processes had the net effect of validating each other.

Once papers were selected, they were reviewed and a summary of the theoretical points relevant to the theme group was recorded in Mendeley for later use in this report and export to Endnote (the bibliographic application used by DRDC Toronto). All papers selected were included in the database and exported to Endnote; copies of each paper were provided to the TA.

3 ANNOTATED BIBLIOGRAPHY

The annotated bibliography is presented in sections corresponding to the different theme groups. One paper is presented on each page. Each paper is introduced with its American Psychological Association (APA) format citation. The next line verifies the theme group(s) to which the paper belongs, followed by a line identifying the keywords identified from reading the paper. Then the paper is summarized in three parts: a first paragraph describing the aims of the paper, one or more paragraphs describing the contents of the paper, and then a final paragraph outlining the conclusions of the authors.

Fifty-eight papers were reviewed in total.

3.1 SA and Cognitive Processes

Twelve papers were reviewed on the subject of SA and cognitive processes.

3.1.1 **Artman, H., & Garbis, C. (1998). Situation Awareness as Distributed Cognition. In T. Green, L. Bannon, C. Warren, & Buckley (Eds), Cognitive and cooperation. *Proc. of the 9th Conference of Cognitive Ergonomics,* 151-156, Limerick: Ireland.**

Category: Cognitive processes, team/shared SA

Keywords: SA, distributed cognition, team/shared SA, dynamic system

The authors of the paper argued that the predominant models of SA were inadequate for the study of systems operated by teams and the distributed approach should be considered.

The authors thought that the distributed cognition approach takes the system as the basic unit of analysis instead of the individual. It focuses on practices of sense-making instead of mental constraints, and it allows the analysis to treat co-operating individuals as a cognitive system.

This research conducted two field studies, one was the team-based SA in the emergency co-ordination center and another was the team SA on a staff command training session. The results of the studies showed that the team's model of what was going on in the system was clearly distributed. They found that the artefacts are integral parts of the whole cognitive system and the way it works. Further, discourse and artefacts have to be actively and collectively interpreted by the team members in order to make sense and to contribute to the construction of shared SA.

Finally, the authors suggested that the future development of the concept of SA in dynamic systems must take into account the distributed nature of cognition.

3.1.2 Endsley, M.R. (2000). Situation Models: An Avenue to the Modeling of Mental Models. *Proc. of the 44-th Annual Meeting of the HFES Conference,* pp, 61-64, Santa Monica, CA.

Category: Cognitive processes, theories/conceptual models

Keywords: Mental Models

This paper explores the concept of mental models and a highly related concept, the situation model. Through the situation model, a method for abstracting user knowledge and creating usable models of their mental model is explored. This technique shows promise as a means of more effectively capturing this elusive construct.

Mental models are the “mechanisms whereby humans are able to generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future states”, while a situation model is “a schema depicting the current state of the mental model of the system”.

The author proposes that the situation model provides a useful window on the mental model. This paper identifies the relationships between the mental model and the situation model (SA): The mental model gets the information from the “Perception” stage in the situation model, and uses the perceived information to interpret the current situation for the “Comprehension” stage in the situation model and finally help the situation model to make the “Projection” about that will happened to the system in the near future. As a result, the situation model is the current instantiation of the mental model which is more general in nature.

Simple articulation of a mental model of some system at any level of detail has proven to be unusually difficult. This paper describes a methodology that represents the mental model in practice, the SA Global Assessment Technique (SAGAT), which assesses a person’s SA (or situation model) during dynamic simulations of a task environment. Using SAGAT, the simulation is stopped at random times and people (usually the operators of the simulated system) are asked questions to determine their SA at that particular point in time. The questions asked are based on analysis of SA requirements for a particular domain, including the questions as to their current perceptions of their environment, their comprehension of the situation and their projections of the future. The SAGAT method is easy to use because it merely requires people to report what they known in terms of their understanding of the situation (decision inputs), rather than why they made a decision.

In SAGAT, the representations of the situation were recorded along with the operators’ decisions as to the correct action for that situation. There data were fed into a neural network to develop a computer model of tactical decision making. When examining a test set of 164 new cases related the threat aircraft, each pilot matched at least one other pilot 74% of the time. From a practical standpoint, the technique provided a

computerized model of expert knowledge that was integrated across multiple experts and delivered a reasonably effective decision support tool.

3.1.3 Gonzalez, C., & Wimisberg, J. (2007). Situation Awareness in Dynamic Decision Making: Effects of Practice and Working Memory. *Journal of Cognitive Engineering and Decision Making,* 1(1), 56-74.

Category: cognitive processes; measures of SA; training

Keywords: working memory, training, situation awareness, dynamic decision making

This paper described two experiments designed to address the effects of task practice on SA, the effect of working memory on SA and the effect of the SA measurement procedure.

The experiments involved a computer simulation of a dynamic decision-making task called the Water Purification Plant (WPP). WPP is a resource allocation and scheduling task that is representative of many real-world tasks.

Thirty-six subjects were randomly assigned to one of two conditions (i.e., covered or uncovered display) and were asked to run the simulation eighteen times. The experiments used two recognized working memory measurements, including the Reading Span Test and the Visual Span Test to measure the ability to process linguistic information. A query method similar to the SAGAT was used to measure SA at the perception, comprehension and projection levels.

The results from this study have clear implications for system design pertaining to the design of learning aids. Data from this study indicate that availability of information at the interface resulted in better SA. The results also suggest that availability of information during practice does not guarantee that SA skills will improve.

Finally, the authors suggest that training efforts and learning experiments need to address the question of knowledge acquisition, particularly what is generated with practice in the task and what is generated by providing strategic information. Individuals need procedural knowledge or strategic information about how to address the task rather than simply practice on the task.

3.1.4 Johannsdottir, K.R. and Herdman, C.M. (2010). The role of working memory in supporting drivers' situation awareness for surrounding traffic. *Human Factors,* 52(6), 663-673.

Category: Cognitive Processes

Keywords: attentional processes; driver behavior; episodic buffer; situational awareness; working memory

The authors investigated the role of working memory in maintenance of SA while engaged in a driving task. Two different 'locations' for SA were considered: forward and backward. Specifically, this work attempted to delineate the contributions of the visuo-spatial and phonological subsystems of working memory implicated in drivers' level 2 SA for surrounding traffic.

The authors described the role of the visuo-spatial sketchpad as being a strong contributor to forward SA, but negligible in rearward SA, largely concluded from other work that noted how much time was spent looking forward and backward when driving. The phonological loop, by elimination, was hypothesized to support rearward SA, and evidence concerning the maintenance of complex verbally coded information was used to support this view.

Two experiments were performed to investigate these hypotheses. In experiment 1 two load conditions were used: a tapping task to load the visuo-spatial sketchpad and a rhyming task to load the phonological loop. Impairment on corresponding hypothesized SA was predicted. They found that the results supported the notion that SA for traffic in the driver's forward view relied on visuospatial coding while SA for traffic in the rear view relied on phonological coding. In experiment 2 stimuli were presented auditorily rather than visually. Load on the subsystems was via a clock task and a word sound task. It was hypothesized that SA for the rear view would be impaired. Results confirmed and extended the results found in experiment 1.

Based on this work, the authors predict that the episodic buffer would be a core mechanism for supporting level 2 and 3 SA. The results may also explain performance decrements when driving and conversing. Nevertheless, the differential involvement of the visuo-spatial sketchpad and phonological loop in driver SA are supported by this work.

3.1.5 Lichacz, F.M.J. (2008). Augmenting understanding of the relationship between situation awareness and confidence using calibration analysis. *Ergonomics*, 51(10), 1489-1502.

Category: measures of SA; theories/conceptual models

Keywords: SA; confidence; calibration analysis

This paper described an experiment to examine the relationship between SA and confidence within a simulated distributed command and control multinational headquarters using calibration analysis.

Eight participants were involved in the experiment, including planners and system analysts in the field of C2. The experiment was conducted with a commercially available software packagem Groove™, a collaborative information environment that allows the user to visually access the linked portions of the database, audio and text chat, email and file-editing capabilities. The task for the participants was to work together as a coalition to halt a pre-crisis situation from developing into a war by identifying and assessing a variety of both military and non-military interventions, within three 5-day periods over 3 weeks, during which the participants focused on different aspects of the multinational operational net assess and deliberate planning process.

The SA probes were administered with SAGAT. Following each query, the participants were required to provide a confidence rating to reflect the accuracy of their response.

The results showed that, overall, the participants attained a mean SA accuracy score of 70.76%, and that the mean confidence rating was 77.95%. The results of calibration analysis demonstrated a trend toward overconfidence in participants' SA responses.

The author concluded that good SA, on its own, is insufficient for good decision making and that confidence has an important role in decision making. Calibration methodology can be used to study the relationship between SA and confidence and therefore could become an integral part of future SA research. This research contributes to the development of models of SA, to the decision making, and to the training programs to improve SA, evaluation of SA and decision making.

3.1.6 O'Brien, K.S., & O'Hare, D. (2007). Situational awareness ability and cognitive skills training in a complex real-world task. *Ergonomics*, 50(7), 1064-91.

Category: training;

Keywords: SA; cognitive skills; planning; training

This article described three experiments that examined the influence of training and planning on SA and performance.

The first experiment trained participants with varying degrees of SA ability to adopt more efficient cognitive and task management strategies to overcome SA ability limitations and improve performance. The Wondrous Original Method for Basic Airmanship Testing (WOMBAT) and the Terminal Radar Approach Control (TRACON) simulation were used as the models of complex real-world task in the experiment. Twenty-eight participants first received TRACON training and testing. Individual WOMBAT and TRACON performance scores were collected and descriptive statistics were calculated. The results showed that given appropriate training, participants were able to overcome performance decrements imposed by limited SA ability.

The second experiment explored the relationship between SA ability, as measured by WOMBAT, and performance in the complex dynamic real-world task of TRACON. Twenty participants were involved in the experiment, based on the SAGAT method. The results showed that the WOMBAT SA ability scores had a strong association with TRACON performance scores. SAGAT scores were also associated with TRACON performance, but not to the same extent as WOMBAT SA ability scores.

The third experiment examined whether planning can ameliorate the SA ability. Twenty-four participants were trained in a manner that was similar to the first experiment. However, this training was constrained in a manner that encouraged planning. The results showed that a training method aimed exclusively at encouraging planning could enhance performance on the complex real-world task of TRACON.

The authors concluded that cognitive skills training and planning could overcome limitations in underlying SA ability and improve performance.

3.1.7 **Rousseau, Robert, Tremblay, Sébastien, Banbury, Simon, Breton, Richard, Guitouni, Adel. (2010). The role of metacognition in the relationship between objective and subjective measures of situation awareness. *Theoretical Issues in Ergonomics Science,* 11(1-2):119-130.**

Category: measures of SA; theories/conceptual models

Keywords: SA; metacognition; measurement; SART; QUASA.

This article described a study on the relationship between subjective and objective measures of SA with two goals: (1) strengthening the factual observation on accuracy (objective measure of SA) and confidence rating (subjective measure of SA); and, (2) enriching the interpretation of the accuracy-confidence relationships with meta-cognition.

An experiment was conducted with a 2-day scenario for a joint military-civilian C2 exercise relating to the crisis management of a large event held in a metropolitan area. Ten experienced joint operations commanders participated in this study with two questionnaires. The SART and QUASA methods were used to measure and analyze SA. Participants were instructed to undertake emergency planning activities relating counter-terrorism and other threats within the context of a joint operation team. Both SART and QUASA questionnaires were administered at the end of each day, and the responses were collated daily.

Based on the analysis of questionnaire group means scores by scenario session, the calculation of a correlation matrix of all questionnaire scores and the analysis of QUASA calibration data, this study did not find the usual weak positive correlation between QUASA confidence and accuracy scores. However, SART SA and SART S and SART did show a significant negative correlation with QUASA accuracy scores.

The authors considered that a plausible explanation about the negative correlation between SART S and QUASA accuracy scores could come from the applying the Koriat et al. (2008) framework about Information-Based (IB) and Experience-Based (EB) metacognitive judgments. The application of the concept of metacognition, namely information- and experience-based metacognitive judgments, to the question of SA subjective self-ratings is a very promising avenue for measurement and also for modeling efforts.

3.1.8 Smith, K., & Hancock, P.A. (1995). Situation Awareness Is Adaptive, Externally Directed Consciousness. *Human Factors,* 37(1), 137-148.

Category: theories/conceptual models; cognitive processes

Keywords: SA; externally directed consciousness; adaptive consciousness; risk space

The authors proposed that SA included consciousness. They introduced and defined the concept of risk space.

SA is adaptive, externally directed consciousness. Consciousness refers to an agent's knowledge-generating behaviour that is within the scope of intentional manipulation. The adaptation here is the process by which an agent channels knowledge and behaviour to attain goals as tempered by the conditions and constraints imposed by the task environment. The phrase 'externally-directed' in the definition indicates that the goal of the behaviour that SA directs must reside in the task environment rather than in the agent's consciousness.

This concept of risk space was treated as a generalization of a mathematical formulation of human performance in process control. An example in commercial aircraft operations was developed within the concept of risk space. This example structures information about the physical airspace to capture the momentary knowledge that drives action and that satisfies the goals and performance criteria for safe and efficient flight.

The authors concluded that SA is a facet of consciousness although it does not necessarily represent all of consciousness in its entirety. Constraints on performance must be made explicit in the environment, and SA is recognized as an invariant component in an adaptive cycle of knowledge, action, and information.

3.1.9 Soliman, A.M. (2010). Exploring the central executive in situation awareness. *Psychological Reports,* 106(1), 105-118.

Category: cognitive processes

Keywords: central executive; working memory

This paper introduced two experiments which explored the relationship between the central executive component in working memory and SA.

The first experiment was to investigate the role of executive control of working memory in a real-life driving simulation. With a typical driving simulation, 148 students were involved in two testing sessions for a SA task and tests of executive ability. The SAGAT was used to measure SA. A one-way analysis of variance was performed and the results showed that participants classified as having low SA performed significantly worse on all executive function tasks compared to those having medium and high SA. This indicates that performance on SA is significant associated with executive function.

The second experiment examined the extent to which taxing the central executive might affect SA. A subset of the participants from the first experiment completed the same driving simulation. The simulation manipulated the loading of the central executive. The results showed that there were no statistically significant differences in rates of infractions for the high SA group with central executive loading.

The author concluded that these findings supported the theories of working memory with information and the role of the central executive and individual differences in SA within the context of dynamic, ill-defined settings.

3.1.10 Stanton, N.A., Salmon, P.M., Walker, G.H., & Jenkins, D. (2009). Genotype and phenotype schemata and their role in distributed situation awareness in collaborative systems. *Theoretical Issues in Ergonomics Science*, 10(1), 43-68.

Category: theories/conceptual models; team/shared SA

Keywords: SA; teams; schema theory; genotypes; phenotypes

The purpose of this article was to formulate an account of SASA in collaborative environments using the ideas of genotype and phenotype schemata and the perceptual cycle model proposed by Niesser (1976). In addition, the study explored the concepts of transactive and compatible SA outlined by Salmon et al. (2008).

Based on Niesser, genotype refers to the wider systemic factors that influence the development of individual cognitive phenomena and behaviour. In contrast, the local, individual-specific manifestation of cognition and behaviour represents the phenotype. Neisser described the concept of the perceptual-action cycle, which included the notion that anticipatory schemata, held by individuals, served to anticipate perception and direct action.

The authors argued that there is significant incongruity between the ideas of team members' genotype and the phenotype schemata driven awareness of a situation and the existing shared SA view.

Based on the schema theory, distributed cognition and cognitive systems engineering, the authors proposed the concept of distributed SA (DSA) that operates at a system level, rather than an individual level. Compatible awareness and transactive tokens are two distinct features in DSA. Compatible SA refers to that each agent has their own awareness compatible with other agents in the system, and transactive SA means that team members may exchange information. The authors developed the propositional network approach to evaluate and represent DSA.

A case study in the energy distribution domain was also described, which showed compatible and transactive features in their theory.

The authors concluded that the ideas presented in this article differ from the dominant models of individual and team SA presented in the literature. However, the authors also argue that they are more appropriate for the study of SA in collaborative environment.

3.1.11 Strauss, R., & Kirlik, A. (2006). Situation awareness as judgment II: Experimental demonstration. *International Journal of Industrial Ergonomics,* 36(5), 475-484.

Category: theories/conceptual models; measures of SA

Keywords: SA; judgment analysis approach; performance measurement; display augmentation

This paper presented the experimental results of modeling and measuring SA as human judgment under uncertainty in conditions where judgment is mediated by a technological interface.

Sixteen student participants were involved in the experimental task requiring stealth judgments to be made in an uncertain environment, based on an experimental simulation. Each participant played the role of as a crewmember aboard a submarine, or ownship, and performed stealth missions. The participant's task was to quickly and accurately assess whether ownship's presence had been detected, on the basis of information presented on a Group Baseline (GBL) situation display or a Group Display Augmentation (GDA). Data were collected and analyzed with the authors' statistical modeling and estimation approach (Kirlik & Strauss, 2006).

The authors found that the enhanced display improved the consistency with which operators perceptually acquired information, however the regression bias increased.

The model was also used to diagnose the factors discriminating high and low performers (i.e., the consistency of cue perception and the ability to consistently apply task knowledge).

The authors concluded that the results demonstrated the utility of a systems, or ecological approach to modeling and measuring SA in interface-mediated, uncertain environment. The authors also identified an issue involving the inconsistency between the regression-based modeling of cognition following Brunswik's probabilistic theory (Brunswik, 1956) and the recent perception or cognition theories. This inconsistency should be addressed further.

3.1.12 Sulistyawati, K., Wickens, C.D., & Chui, Y.P. (2011). Prediction in Situation Awareness: Confidence Bias and Underlying Cognitive Abilities. *The International Journal of Aviation Psychology,* 21(2), 153-174.

Category: cognitive processes; measures of SA

Keywords: SA; confidence bias, prediction; SAGAT; air combat simulation; cognitive ability; performance

This paper reported the results of a study on understanding the cognitive construct of prediction in SA with the SAGAT on an air combat simulation.

Sixteen fighter pilots participated in the air combat environment simulated on a PC-based simulation engine called Falcon 4.0 to test pilots' cognitive ability. Two individual missions were designed by the Subject Matter Experts (SME), reflecting typical scenarios used in the air force training. Pilot SA levels 1, 2 and 3 were assessed using SAGAT. Overconfidence, cognitive abilities and performance were also assessed

The results considering the three levels of SAGAT queries supported the idea that people are generally poorer in predicting future status compared to understanding the present situation, however the difference in this prediction ability is the one that will differentiate good from poor performance. There are tendencies for people to be more overconfident on their Level 3 than Level 1 and 2 SA. Further, higher overconfidence is associated with worse performance. These findings collectively justify the cognitive significance of prediction in SA.

3.2 SA Theories/Conceptual Models

Eighteen papers were reviewed on the subject of SA theories and conceptual models. Rather than repeat summaries of papers, only a reference will be given if a paper has already been covered in earlier theme groups.

3.2.1 **Artman, H., & Garbis, C. (1998). Situation Awareness as Distributed Cognition. In T. Green, L. Bannon, C. Warren, & Buckley (Eds). Cognitive and cooperation. *Proc. of the 9th Conference of Cognitive Ergonomics,* 151-156, Limerick: Ireland J.**

3.2.2 **Bedny, G., & Meister, D. (1999). Theory of activity and situation awareness. *International Journal of Cognitive Ergonomics,* 3(1), 63-72.**

Category: cognitive processes, theories/conceptual models,

Keywords: activity theory, SA, relationship between activity theory and SA

The authors of this paper were the research scientists in Russian Activity Theory. They tried to establish a relationship between the Russian Activity Theory and SA; they considered SA as a part of the activity theory.

The category of activity plays a major role in Russian psychology. The basic structure components of activity include a) goals as an ideal image or logical representation of future results of activity, b) motives that direct individuals toward the goal, and c) methods of activity that include logically ordered systems of actions that permit one to achieve conscious goals. There are three components or stages to represent the activity, including an orientational component representing the dynamic world, an executive component consisting of decision-making and performance of actions, and an evaluative component for the assessment of activity results.

The authors in this paper treated SA as one important functional mechanism of reflective-orientational activity in their activity theory, which provided a conscious and dynamic orientation in the situation.

Further, based on functional analysis, the structure of activity can be described as a system of interconnected function blocks, including conceptual model, image-goal and subjectively relevant task conditions for the orientational activity. By contrast, the last function block has more dynamic and manipulable features. It includes within itself imaginative and logical components. The imaginative components of dynamical reflection are called the operative image. The logical-conceptual components of dynamic reflection are what Endsley called SA.

This paper mainly described the activity theory, and tried to explain where the SA is in their activity theory, without describing the association at detailed levels.

3.2.3 Bolstad, C.A., Cuevas, H.M., Gonzalez, C., & Schneider, M. (2005). Modeling Shared Situation Awareness. *Proc. of the 14th Conference on Behavior Representation In Modeling and Simulation (BRIMS),* Los Angeles, CA.

Category: team/shared SA; theories/conceptual models; perspective/approaches

Keywords: SA, social network analysis, distributed team performance.

This paper described a computational model of shared SA by integrating the theoretical conceptual model of SA proposed by Endsley and the concepts in Social Network Analysis (SNA) (Dekker, 2002).

The computational model was based on the data collected from a simulated training exercise, designed to mimic real life events in a military personnel recovery center. Sixteen active servicemen and 3 DoD (Department of Defense) contractors (mean age = 33.85) participated in this study. Predictor variables for the computational model were drawn from participants' responses to the background data and communication questionnaires and their team assignments during the exercises.

SA was measured during the exercise using SAGAT.

They defined five factors to predict shared SA, including social network distance, physical distance, rank similarity, branch similarity, and experience similarity. Based on the collected data, the scores of the five factors were computed.

The results of regression analysis showed that the physical distance (i.e. whether participant pairs were co-located or distributed) made a significant unique contribution to the prediction of shared SA.

This research also suggested that to ensure successful distributed team performance, team members need access to technological tools that support shared SA, providing important information on changes within the team.

3.2.4 Endsley, M.R. (2000). Theoretical Underpinnings of Situation Awareness: A Critical Review. In *Situation Awareness Analysis and Measurement,* 1-24. Mahwah, NJ: LEA.

Category: cognitive processes; theories/conceptual models; measures of SA

Keywords: Review of SA, SA definition, cognitive process, measurement of SA

This paper reviewed the main points and clarified some significant concepts of SA. They were summarized as follows:

- **Introduction**
  - **What is SA?:** SA is described 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;
  - **SA and Decision Making:** SA is a stage separate from and before decision making and performance;
  - **Who needs SA?** SA may be used in many areas (e.g. system design, medicine, sports, etc.); and,
  - **How do we get SA?** SA is derived from all of our various sources of information through visual, aural, tactile, olfactory or taste receptors.
- **Theories of SA**
  - **Working Memory and Attention:** Attention is important for SA and the limits of working memory pose a constraint of SA. Methods are needed to reduce the working memory load;
  - **Long-term Memory & Working Memory Connection:** SA is not a function of working memory or long-term memory. SA is a unique product of external information acquired, working memory processes and the internal long-term memory stores activated and brought to bear on the formation of the internal representation;
  - **Long-term Memory, Mental Models and SA:** Long-term memory stores in the form of mental models of schema are hypothesized to play a major role in dealing with the limitations of working memory;
  - **Pattern Matching and Other Cognitive Processes:** Pattern matching goes hand-in-hand schema and mental models in facilitating the development of SA.
  - **Goals:** Goals are central to the development of SA;
  - **Expectations:** Expectations influence the formation of SA;
  - **Automaticity:** Automaticity is another mechanism developed with experience that can influence SA; and,

- **Processes vs. Product: Situation Assessment and SA:** SA is the product of situation assessment.

- **Measurement of SA**

  - **Why Measure SA?** The measurement of SA provides a useful index for evaluating system design and training techniques and for better understanding human cognition;
  - **Requirements for SA Measures:** Validity and reliability must be established for any SA measurement technique that is used;
  - **Implications of SA Theory for Measurement of SA:** processes vs. states; SA, decision making, and performance disconnect; attention; memory; workload;
  - **How much SA is enough?** There is really no set threshold of SA that can guarantee a given level of performance. More SA is always better; and,
  - **Conclusions**: Numerous approaches to measuring SA have been proposed, each of which may have advantages and disadvantages.

3.2.5 Endsley, M.R. (1995). Toward a Theory of Situation Awareness in Dynamic Systems. *Human factors.* 37(1), 32-64.

Category: Theories/Conceptual Models;

Keywords: 3-level model of SA, perception, comprehension, projection.

In this paper, the author originally proposed the popular 3-level model of SA (i.e., perception, comprehension and projection).

The author first defined the role of SA in the overall decision-making process. According to this model, a person's perception of the relevant elements in the environment, as determined from system displays or directly by the senses, forms the basis for his or her SA. Action selection and performance are shown as separate stages that will proceed directly from SA.

The author normally defined the SA as follows: "Situation awareness is the perception of the elements in the environment within a volume of time and space (Level 1 SA), the comprehension of their meaning (Level 2 SA), and the projection of their status in the near future (Level 3 SA)."

Based on the definition of SA, the author discussed some important individual and environmental factors affecting SA, including attention, working memory, long-term memory, mental models, goal-directed behaviour, time, space, workload, stress, system complexity, and automation.

Based on this model, a taxonomy of SA errors was also generated (e.g. incomplete information, inaccurate SA, incorrect default values, inability to comprehend the meaning data, etc.).

3.2.6 **Endsley, M.R., Holder, L.D., Leibrecht, B.C., Garland, D.J., Wampler, R.L., & Matthews, M.D. (1999). *Modeling and Measuring Situation Awareness in the Infantry Operational Environment.* Unpublished report.**

Category: Measures of SA; theories/conceptual models

Keywords: SA measures, infantry SA model, individual SA, team SA

This is a research report sponsored by the U.S. Army Research Institute for the Behavioral and Social Sciences.

The goal of the research was to develop a model and measures of SA as a foundation for developing improved techniques and tools to enhance SA in the Infantry operational environment.

A needs-based methodology was implemented by the project team to analyze operational Infantry requirements related to SA. Doctrinal and historical documents were reviewed and an Infantry-focused model of SA was developed. Existing models were adapted to generate one model for individual SA and a second model for team SA and both were integrated into a unified framework. Next, they analyzed the pros and cons of available SA measurement techniques. Finally, they developed and prioritized recommendations for future SA research and development by analyzing operational needs, knowledge gaps, and high-payoff targets.

The results of this project provide useful information for Army developers and trainers to create innovative training programs for enhancing battlefield SA. Equally important, the results may lead to enhanced approaches and techniques for determining the SA impact of advanced information technologies. Finally, the recommendations for future research may help Army planners and decision makers when faced with the challenges on the future battlefields.

3.2.7 Gonzalez, C., Saner, L., Endsley, M.R., Bolstad, C.A., & Cuevas, H.M. (2009). Modeling and Measuring Situation Awareness in Individuals and Teams. *Proc. of the Advanced decisions architectures for the warfighter: Foundations and technology,* pp, 257-282.

Category: Perspective/approaches; team/shared SA; measures of SA

Keywords, computational model of SA, 3-level model of SA, ACT-R, SAGAT, goal-directed task analysis

This paper described an integrated framework for individual and team situation awareness by combining the 3-level model of situation awareness, goal-directed design, team SA, social network analysis, and ACT-R.

The authors used the ACT-R architecture to develop a Cognitive Models of Situation Awareness (CMSA) at individual level. The cognitive models consist of a recognition, assessment, prediction and control modules. The recognition module gathers and encodes visual sensory information from the environment and encodes the information into ACT-R representations. The assessment module represents and manipulates information and updates, and maintains information on the environment. The predication module constructs and evaluates hypotheses about the function of an entity in a plan, to determine the probability and possible success of a course of action. The control module then provides the capability to select actions that will change the state of the world.

This paper also described the design of SA, team SA and measures of SA. The Goal-Directed Cognitive Task Analysis (GDTA) was used for test cases to optimize the design of simple Graphic User Interface. The Social Network Analysis (SNA) theory was used to develop the computational models of team and shared SA in this framework. The method used to measure individual and team SA was the Situation Awareness Global Assessment Technique (SAGAT).

The computational representations of different aspects of SA including the cognitive, design and organizational aspect of SA in this paper demonstrated the complexity in representing and reproducing human SA at different levels of specificity. Their efforts also suggested that the development of SA measures, at both the individual and organizational levels, be essential to make progress in assessing SA, both behaviorally and computationally.

3.2.8 Hourizi, R., & Johnson, P. (2003). Towards an explanatory, predictive account of awareness. *Computers & Graphics,* 27(6), 859-872.

Category: theories/conceptual models

Keywords: awareness, SA, predictive model, design

This paper described an experiment that investigated the utility of an explanatory and predictive account of awareness in the design of complex human-computer interaction.

The scenario chosen in the experiment was an animated aircraft descent from a starting altitude of 10,000 ft. Participants were asked to execute a series of instructions to descend and ensure that the aircraft was travelling towards an airport, which was below them and slightly to their right. The automation would make alterations (i.e., interventions) to the course of the flight, such that the aircraft would start to move away from the fictional airport. The warning information on the intervention then was added to the display. Finally, the participants' awareness of ongoing flight was measured by recording both reported observations that "something unexpected was happening" and subsequent participant activity (if any) to correct the problem.

The authors generated three hypotheses: 1) The inclusion of explicit information about autopilot activity will increase the number of reported observations that such activity had occurred; 2) The inclusion of a specific semantic link between the warning signal given to participants and the underlying autopilot activity will increase the participants' understanding; and, 3) If the number of reported interventions is similar in the two conditions involving warnings signals with and without more semantic links, then the absolute number of correction observed in the warning signals with more semantic links will be significantly higher than the warning signals without semantic links.

The authors concluded that the results of experiment showed initial support for these hypotheses.

3.2.9 Kirlik, A., & Strauss, R. (2006). Situation awareness as judgment I: Statistical modeling and quantitative measurement. *International Journal of Industrial Ergonomics.* 36(5), 463-474.

Category: Theories/conceptual models; measures of SA

Keywords: SA; operator modeling; judgment; performance measurement; statistical model of SA

This article proposed a quantitative conceptual model that viewed SA as the degree of correspondence between a set of human judgments and the distribution of true system or environmental states or events being judged.

The authors first identified four main issues that influenced their SA modelling and measurement, including a system approach capable of representing and decomposing both the technological and psychological contributions to SA, recognizing uncertainty, a diagnostic approach and a functional function.

The proposed approach was based on the Lens model of judgment (Brunswik, 1956), the mathematical formation for Brunswik's model (Hursch et al., 1964 & Tucker, 1964), the diagnostic measure of weather forecasting skill (Murphy, 1988), the combination of the Lens model and Murphy's skill measure (Stewart, 1990), and finally, the representation of sensing and information processing technology for modeling interface-mediated judgment (Stewart & Lusk, 1994). These statistical modeling and estimation techniques decompose SA into eight individually measurable components for engineering analysis and design, including skill score, environmental predictability, fidelity of the information system, knowledge, consistency of information acquisition, consistency of information processing, regression bias, and base rate bias. They eventually combined the eight quantitative components into an equation named the expanded Lens model for SA.

The authors also compared their model with some recognized models of SA (e.g., Endsley's three-level model and the SASAGAT, Parasuraman's Human-Automation Interaction (HAI), and Klein's Naturalistic Decision Making (NDM).

Finally, the authors proposed that their quantitative model should be considered as an addition to the human factors tool box, as advances in theory and application depend on advances in measurement.

3.2.10 **Lichacz, F.M.J. (2008). Augmenting understanding of the relationship between situation awareness and confidence using calibration analysis. *Ergonomics*, 51(10), 1489-1502.**

3.2.11 **McGuinness, B. (2004). Quantitative Analysis of Situational Awareness (QUASA): Applying Signal Detection Theory to True/False Probes and Self-Ratings. *Proc. of the 9-th International Command and Control Research and Technology Symposium,* Copenhagen, Demark.**

Category: measures of SA; perspective/approaches

Keywords: assessment of SA; probe techniques, self-rating techniques, calibration; signal detection theory, quantitative analysis

This paper described an approach for measurement of SA by combining the recognized probe or query techniques and the self-ratings techniques with the signal detection theory and the calibration analysis.

The author argued that SA seems to have a twofold effect on decision-making in the form of actual SA and perceived SA. While the probe techniques specially address actual SA and the self-rating techniques specifically address perceived SA, the combination of both techniques can provide a more holistic measurement of SA.

The author proposed a technique called the Quantitative Analysis of SA (QUASA) to extend the current approaches to SA measurement. The proposed model used true/false queries to model the probe techniques and used the confidence for each and every true/false probe response to characterize the self-rating technique. In this study, SA accuracy is quantified as the proportion of probes answered correctly while perceived accuracy is obtained from self-ratings of confidence in individual probe response. The Signal Detection Theory (SDT) is used to measure the actual SA accuracy. The calibration analysis is used to examine the relationship between the actual SA and perceived SA.

This paper also described an experiment on the ‘operational net assessment’ process with 45 subjects and over 100 true/false probes, which yielded a set of useful and potentially insightful quantitative results.

Finally, the author concluded that the impetus for the technique is twofold: first, the intuition that combining subjective ratings simultaneously with individual SA probes gives a much fuller picture of SA; second, the finding that applying SDT analysis to probe results yields sensitivity and bias statistics which give insights into subjects’ SA what would be unavailable using percentage correct alone.

3.2.12 Ntuen, C.A. (2006). The Knowledge Structure of the Commander in Asymmetric Battlefield: The Six Sights and Sensemaking Process. *Proc. of the 12th International Command & Control Research and Technology Symposium (CCRTS)*, San Diego, CA.

Category: SA theories/Conceptual models

Keywords: cognitive domain issues, C2 modeling and simulation, C2 analysis

This paper presented the six human 'sights', including insight, hindsight, foresight, outsight, short-sight and oversight, and their influences on battle sensemaking situations and decision making.

The author described each of the six sights. (1) **Insight**, a type of tacit knowledge, is our ability to discern the true nature of a situation, which supports meta-cognition with mental models; (2) **Hindsight**, a kind of lessons-learned knowledge embodied in historicity, is the perception of the significance and nature of events after they have occurred. It can be used to minimize risks in decision making; (3) **Foresight** is the cognitive structure that contains level 3 SA elements defined by Endsley, which allows the sensemaker to anticipate, envision, and form notional expected goals about the situation or context of interest; (4) **Outsight** is about understanding the ecological niche and how it influences the commander's sensemaking process; (5) **Short-sight** is the sight that controls the short-term decision making by the expert. The short-sighted sensemaker does not see the "big" picture; hence all thinking is local for an immediate effect-based operation; and, (6) An **Oversight** knowledge structure is used by experts to review and assess errors that occur during problem-solving or decision-making.

The author surmised that these sights represent the dynamic knowledge structures of the commander while developing plans for an on-going operation.

3.2.13 **Rousseau, R., Tremblay, S. & Breton, R. (2004). Defining and Modeling Situation Awareness: A Critical Review. In Banbury & S. Tremblay (Eds), *A Cognitive Approach to Situation Awareness: Theory and Application,* pp 3-21. Ashgate: Aldershot.**

Category: theories/conceptual models; team SA

Keywords: definitions of SA; modeling SA; team SA; review

The authors reviewed the definitions, approaches, models and team SA

The definitions of SA were classified as state-based and process-based SA.

The state-based definitions consider SA as a label for cognitive processing activities in fields of practice (Sarter and Woods, 1995) or a state of knowledge (Endsley, 1988, 1995) achieved by a situation assessment process. The authors analyzed the potential confusion of the state-based definitions of SA (e.g., SA and situation assessment).

The process-based approaches were reviewed and categorized as operator-focused approaches and situation-focused approaches. An operator-focused approach concerns the set of cognitive processes supporting the production of the mental representation corresponding to the SA state. A situation-focused approach deals with the mapping of the relevant information in the situation onto a mental representation of that information within the agent. The distinction between operation and situation focused approaches helps reframe the classical state-process distinction.

The authors reviewed and classified the models of SA as the descriptive models describing the actual SA process and the prescriptive models representing SA with computational or numeric methods. Examples of descriptive models include the hierarchical and linear model from Endsley (1988, 1995) and a network of parallel functions from McGuiness & Foy (2000). The SAMPLE (Zacharias et al., 1996) and MIDAS (Shiveley et al., 1997) are two examples of prescriptive models.

Based on a brief review to team SA, the authors thought individual SA, communication and coordination are influential factors to team SA. However, there are still many challenges to understanding shared cognition and its relationship to team SA research.

3.2.14 **Rousseau, Robert, Tremblay, Sébastien, Banbury, Simon, Breton, Richard, Guitouni, Adel. (2010). The role of metacognition in the relationship between objective and subjective measures of situation awareness. *Theoretical Issues in Ergonomics Science,* 11(1-2):119-130.**

3.2.15 **Salmon, P. M., Stanton, N.A., Walker, G.H., Baber, C., Jenkins, D.P., McMaster, R., & Young, M.S. (2008). What really is going on? Review of situation awareness models for individuals and teams. *Theoretical Issues in Ergonomics Science,* 9(4), 297-323.**

Category: team/shared SA; theories/conceptual models

Keywords: SA; collaborative activity; teams; distributed SA

This article reviewed the existing theories and models of individual SA and team SA.

Regarding the definitions of SA, the authors reviewed a group of definitions, and concluded that it is generally agreed that SA refers to an individual's dynamic awareness of the ongoing external situation.

The authors examined seven individual SA theories, including the Three-Level Model (Endsley, 1995), the Perceptual Cycle Model (Smith & Hancock, 1995), the Theory of Activity Model (Bedny & Meister, 1999), the model of Sarter & Woods (1991), the model of Adam et al. (Adams, Terney & Pew, 1995), the Predictive Account of Awareness (Hourizi & Joinson ,2003) and the model of Taylor (1990). They compared the models with a group of features, including domain of origin, domain of application, theoretical underpinning, process, composition, novelty, measure, process or product, citation, main strengths, and mean weakness. Finally, the authors considered that Smith and Hancock's and Adams et al.'s models are perhaps the most useful since they cater to the dynamic aspects of SA. In contrast, Endsley's three-level model offers a very intuitive description of SA, which allows researchers to measure it simplistically and also to abstract SA requirements at each level.

The authors also reviewed seven theories or conceptual models for SA in collaborative systems including the models from Endsley & Robertson (2000), Endsley & Jones (2001), Salas et al. (1995), Wellens (1993), Artman & Garbis (1998), Shu & Furuta (2005), and Santon et al. (2006). They compared the models with the same group of features used in the review of individual SA models above. The authors concluded that most of the existing team SA or shared SA models are impractical when applied to the description and assessment of SA in collaborative environments. They proposed that the Distributed SA (DSA) theory and models proposed by Artman and Garbis (1998) and Stanton et al. (2006) are the most suitable.

3.2.16 Salmon, P.M., Stanton, N.A., & Young, K.L. (2011). Situation awareness on the road: review, theoretical and methodological issues, and future directions. *Theoretical Issues in Ergonomics Science,* May 2011, 1-21.

Category: perspectives/approaches; theories/conceptual models

Keywords: SA; road safety; system approach; drivers; SA measurement

The authors in this paper reviewed the models, measures and applications of SA, with a particular focus on the road-transportation domain.

The authors reviewed SA models applied in driving assessments, including their theoretical underpinning, the process of acquiring SA and composition of SA and their applications in research including the main strengths and weaknesses within the context of driving. These related models include the three-level model (Endsley 1995), the information processing model of SA (Mathews et al., 2001), and the Distributed SA (DSA; Walker et al., 2009). The authors concluded that while no model of SA in the road transport domain was prevalent, the psychological perspective (i.e., the three-level model), was clearly preferred in the attempt to define or conceptualize driver SA.

This paper summarized five measurement methods including SAGAT (Endsley, 1995), the SART) (Taylor, 1990), the Eye tracker method, the Propositional Networks (Salmon et al., 2009) and the Recall and Imbedded Task Measures (Gugerty, 1997). Of the methods, the SAGAT had been the most commonly adopted measure of driver SA. In addition, the Propositional Networks, and the Eye Tracker method were also popular for measuring driver SA.

The majority of SA-related applications in road transport had been driver-centric, focusing on the level of SA held by drivers in terms of the factors affecting it and the effects on driver performance of degraded SA. Broadly, these could be grouped into research exploring the effect of in-vehicle technologies on driver SA, the effect of different forms of driver training on driver SA and the influence of driving experience on driver SA.

The authors finally concluded that this contribution could only be made following a shift in the theoretical and methodological approaches taken; specifically, systems approaches to describing the modeling SA, popular node in other complex safety critical domains, should lead future SA investigations in road transport.

3.2.17 Sharma, S., & Ivancevic, V.G. (2010). Nonlinear dynamical characteristics of situation awareness. *Theoretical Issues in Ergonomics Science*, 11(5), 448-460.

Category: theories/conceptual model;

Keywords: bifurcation; chaos; decision-making; nonlinear dynamics; SA

The authors proposed a quantitative model to explore the dynamic and nonlinear characteristics of SA.

To model the perception level in Endsley's three-level SA theory, the authors used the following equation to describe a one-dimensional nonlinear model of SA dynamics:

$$S_{n+1} = BS_n (1 - S_n)$$

where S_{n+1} is the next SA, B is the SA growth-rate parameter representing the amount of useful information flow per unit time, S_n is the present SA, and $(1 - S_n)$ keeps the maximum conceivable SA within limits by accommodating the influence of factors such as perceptual limitations, memory capacity, memory loss, mental fatigue, vigilance and cognitive distractions.

The n-dimensional time-varying SA dynamic model, S_t is the sum of S_k, $k = 1, 2, \ldots, n$, at the time t.

The following equation is used to represent the n-dimensional time-varying SA dynamics model:

$$S_i^{t+1} = \sum_{k=1}^{n} B_{ik}(t) S_k^t (1 - S_i^t)$$

where the upper index denotes a discrete time-evolution steps, while the lower indices I, k = 1, …, n represent SA dimensions (e.g. perceptual limitations, memory capacity, memory loss, etc.).

The authors also analyzed various characteristics of the model, including steady state behaviour, bifurcation and chaos, and the Lyapunove exponent as a function of the growth-rate parameter.

The authors concluded that SA is nonlinear dynamical and possibly chaotic. Using an abstract mathematical model of SA dynamics, and later expanding its mathematical strength to further accommodate various SA dimensions, the study suggested the quality of SA depends on the growth-rate parameter, which represents the amount of useful information supplied per unit time.

3.2.18 **Stanton, N A., Stewart, R., Harris, D., Houghton, R.J., Baber, C., McMaster, R., Salmon, P.M., Hoyle, G., Walker, G.H., Young, M.S., Linsell, M., Dymott, R., & Green, D. (2006). Distributed situation awareness in dynamic systems: theoretical development and application of an ergonomics methodology. *Ergonomics,* 49(12-13), 1288-1311.**

Category: theories/conceptual model; team/shared SA

Keywords: agents; system theory; command and control; SA; teams

The authors in this paper proposed a theory for Distributed SA (DSA) which is system oriented, rather than individual oriented.

They proposed a set of tenets to form the basics of their theory, including that (1) SA is held by human and non-human agents; (2) different agents have different views on the same scene; (3) whether or not one agent's SA overlaps with that of another depends on their respective goals; (4) communication between agents may be non-verbal behaviour, customs, and practice; (5) SA holds loosely coupled systems together; and, (6) one agent may compensate for degradation in SA in another agent. The authors proposed that the existing "shared SA approaches" could misdirect attention to inappropriate aspects of the tasks, and compatibility should be considered in distributed environments.

The DSA methodology comprises three main parts, including knowledge elicitation, knowledge extraction, and knowledge organization and activation. The knowledge owned by each party in each phase of the operation is elicited with the Critical Decision Method (CDM). The 'knowledge objects' are extracted by content analysis. The relations between knowledge objects and their activation are represented by propositional networks that are a kind of semantic networks that describe any given situation.

A case study in a Type 23 frigate operations control room at HMS Dryad was also described in the paper, which consisted of a social network representing communication relations between people in the system, a task network showing the relationships between goals of different agents in the system, and a knowledge network representing the relationships between classes of information that the system knows about in order to perform effectively. The authors also analyzed the core knowledge objects in the case study.

The authors concluded that the distributed cognition approach had been successfully used to analyze the cognitive properties of a variety of environments, and had implications for the design of the working environment and human-computer interaction. Finally, the authors indicated that further evidence was required to substantiate this theory.

3.3 SA Perspectives/Approaches

Twelve papers were reviewed on the subject of SA perspectives and approaches. Rather than repeat summaries of papers, only a reference will be given if a paper has already been covered in earlier theme groups.

3.3.1 **Bolstad, C.A., Cuevas, H.M., Connors, E.S., Gonzalez, C., Foltz, P.W., Lau, N.K.C., & Warwick, W.J. (2010). Advances in Modeling Situation Awareness, Decision Making, and Performance in Complex Operational Environments. *Proc. of the HFES conference,* pp, 1047-1051, Santa Monica, CA.**

Category: perspective/approaches

Keywords: modeling, SA, decision making, performance.

This paper consisted of 5 research abstracts about modeling SA, decision making and performance. The distinctive aspects of each research were summarized as follows:

1. Modeling SA Using Fuzzy Cognitive Mapping (Connors, E.S): Linking cognitive models of SA to operator goals and information requirements;

2. Methodological Issues in Acquiring Empirical Data to Model SA in Nuclear Process Control (Lau, N.K.C.): Incorporating operator self-awareness (metacognition) into models of SA;

3. Automated Modeling of SA and Other measures of Team Performance Using the TEAMCOMM Toolset (Foltz. P.W.): The value of communication analysis as a means of developing predictive models of SA and decision making performance;

4. Instanced-Based Learning Models of Decision Making (Gonzalez, C.): The importance of comparing different modeling approaches to represent decision making; and,

5. Back to level 0: Understanding the Flow of Information in Complex, Networked Environments (Warwick, W.J.): Modeling how information is acquired and used to support decision making, instead of focusing only on decision outcomes.

The authors concluded that: “developing cognitive models of human performance is quite challenging, and will become even more so as the tasks human perform continue to increase in complexity.”

3.3.2 Bolstad, C.A, Riley, J.M, Jones, D.G, & Endsley, M.R. (2002). Using Goal Directed Task Analysis with Army Brigade Officer Teams. *Proc. of the 46-th Annual Meeting of the HFES conference,* pp, 472-476, Santa Monica, CA.

Category: perspectives/Approaches; Team/Shared SA

Keywords: Goal Directed Task Analysis (GDTA), SA requirements,

This paper discussed how the GDTA may be used to analyze the shared information requirements of teams of various types, referred to as shared SA or collaborative SA to support important team processes and interactions.

The GDTA was conducted based on interviews with four key brigade positions: Intelligence Officer, Operations and Training Officer, Logistics Officer and Brigade Engineer. The goal hierarchies included SA requirement. These goal hierarchies were then further refined and validated by Brigade Officers. Further analysis identified shared information requirements.

The analysis of the individual SA requirements revealed many similarities across positions. The GDTAs were also used to evaluate overlapping information requirements. Overlaps in the goals of each team member exist in that they all share a common goal.

The authors concluded that the GDTA was very valuable for understanding the SA requirements of Army Brigade Officers and the information that needs to be shared between them. The shared requirements can also be used to develop methods aimed at increasing shared SA between these Brigade Officers, which will be increasingly important as future operations are expected to become more distributed.

3.3.3 Dekker, S.W. A., Hummerdal, D.H., & Smith, K. (2010). Situation awareness: some remaining questions. *Theoretical Issues in Ergonomics Science,* 11(1-2), 131-135. London: Taylor & Francis.

Category: cognitive processes; theories/conceptual models

Keywords: ontology; objectivism; normativism; elementarism

The authors questioned the current research on SA based on the following three aspects.

The nature of experience: The authors used William James' 'pailsful, spoonsful, quartpotsful, barrelsful and other moulded forms of water" as an example to show that the researchers on SA overlook the context of consciousness. They proposed an alternative ontology which depicts the dynamic transaction or conversation between the situation and the awareness as the only relevant reality. None of the current descriptions of SA in the literature has the ontological perspective to match James' dynamics of experience or the Weberian view of the social order. The fundamental assumption of a separation between observer and observed remains.

The subjective experience and normative objectivity: A second question centred on the implicit normativism in many conceptualizations of SA. The authors proposed that the operator's understanding of the world can be contrasted against an objectively available state of that world. This position is challenging as it posits that the ability to provide a full accounting of goal-directed action in the pursuit of task goals has limited utility to the operator during the event. Both task analysis and its step-child, SA, too easily dismiss the situation from the awareness they aim to describe.

The elementarism or meaningful: the authors thought that the idea of elements as the starting point of perceptual and meaning-making processes in SA was inappropriate for achieving a better understanding of human consciousness in complex systems. What observers see are entities and contexts, not their parts.

3.3.4 **Endsley, M.R. (2000). Theoretical Underpinnings of Situation Awareness: A Critical Review. In *Situation Awareness Analysis and Measurement,* 1-24. Mahwah, NJ: LEA.**

3.3.5 **Endsley, M.R. (2001). Designing for Situation Awareness in Complex System. *Proc. of the Second international workshop on symbiosis of humans, artifacts and environment,* Kyoto, Japan.**

Category: perspective/approaches

Keywords: design of SA, SA requirements analysis, SA-oriented design, SA design evaluation

This paper provided a high-level guidance for incorporating SA considerations into the design process, including a determination of SA requirements, designing for SA enhancement, and measurement of SA in design evaluation.

The author suggested that a form of Cognitive Task Analysis called a GDTA be used for the SA requirement analysis. In such analysis, the major goals of a particular job class are indentified, along with the major sub-goals necessary for meeting each of these goals. This analysis is based on goals or objectives, rather than tasks. This is because goals form the basis of decision making in many complex environments.

The guidance for SA-oriented design includes direct presentation of higher level SA needs, goal-oriented information displays, support for global SA, determining critical cues of key features, removing unrelated information, and support for parallel processing.

Regarding the SA design evaluation, the author recommended the freeze-based computerized SAGAT method to assess SA.

3.3.6 Flach, J.M. (1995). Situation Awareness: Proceed with Caution. *Human Factors,* 37(1), 149-157.

Category: cognitive processes

Keywords: counterpoint to SA, phenomenon identification, cause of observations, circular reasoning

This paper was an invited article to provide an editorial counterpoint to the other articles in a special SA issue in the journal of *Human Factors*, 37(1), 1995.

The author discussed the SA concept in the light of Benton J. Underwood's discussion about psychological Level-2 (i.e., phenomenon identification) and Level-3 (i.e., a cause for the observation indicating the phenomenon) concepts.

The author proposed that as a Level-2 concept, SA is an invitation to take a new look at human performance. This new perspective spans the human-environment system and encourages a deep appreciation for the rich interactions between human and environment and among perception, decision making, and action. As a Level-2 concept, SA places human factors at the forefront of human performance theory.

However, as a Level-3 concept the statement from the SA community that SA or loss of SA is the leading cause of human error, SA is likely to be an obstacle to progress both in theory and application because it leads to circular arguments (i.e., SA is presented as the cause of itself).

The author concluded that, as a Level-2 concept (i.e., phenomenon identification), SA requires further research to discover causal relationships between the design of human-machine systems and the resulting performance.

3.3.7 Salmon, P.M., Stanton, N.A., Walker, G.H., & Green, D. (2006). Situation Awareness Measurement: A review of applicability for C4i environments. *Applied Ergonomics,* 37(2), 225-238.

Category: measures of SA; perspective/approaches

Keywords: SA; measurement; C4i systems

This paper focused on the measurement of SA, in particular, for the environments of C4i (i.e., Command, Control, Communication, Computers and Intelligence).

The authors first identified the requirements of SA measurement in C4i systems, including that the technique should be capable of measuring SA simultaneously at different geographical locations, and capable of measuring both individual and team or shared SA.

The authors then reviewed 7 categories of existing SA measurement techniques including SA requirement analysis, freeze probe techniques, real-time probe techniques, self-rating techniques, observer-rating techniques, performance measures and process indices (eye tracker).

The author compared and summarized the results of 17 methods and concluded that in their current format the existing SA measurement approaches were inadequate for the measuring SA in C4i environments. This conclusion was based on the understanding that all methods focused upon the assessment of individual SA and their distinct flaws that could potentially hinder the reliability of the SA data obtained.

Finally, the authors proposed that a multiple-measure or toolkit approach of measurement techniques may be the most appropriate way to measure SA in C4i environment.

3.3.8 **Salmon, P.M., Stanton, N.A., & Young, K.L. (2011). Situation awareness on the road: review, theoretical and methodological issues, and future directions. *Theoretical Issues in Ergonomics Science,* May 2011, 1-21.**

3.3.9 **Stanton, N.A. (2010). Situation awareness: where have we been, where are we now and where are we going? *Theoretical Issues in Ergonomics Science,* 11(1-2), 1-6.**

Category: theories/conceptual models; team/shared SA; measures of SA;

Keywords: SA; perspective on SA; team SA; measures of SA; challenges for SA research

The author summarized eight articles on SA in the special issue of the Theoretical Issues in Ergonomics Science, April, 2010. The eight papers were classified into four main areas including perspectives on SA, team SA, measures of SA, and future challenges of SA research.

There were two papers related to the perspectives on SA, including the “Capturing the dynamics of attentional control from individual to distributed systems” from Woods & Sarter (2010), and “Is situation awareness all in the mind?” from Stanton et al. (2010). Woods & Sarter (2010) proposed that design for tacit skill development offers a new way of thinking about distributed SA between human and technological agents. Stanton et al. (2010) took a systems perspective on SA, and proposed the interactive systems perspective of distributed SA provided that most complete and comprehensive account of SA.

The three papers for team SA included the “Approaches to understanding, analyzing and developing SA” from Patrick and Morgan (2010), the “Is it really better to share?” from Salmon et al. (2010) Band “The role of SA for understanding signalling and control in rail operations” from Golightly et al. (2010). Patrick and Morgan (2010) reported a “process tracing” approach to show how moment-by-moment millisecond activity of a team can be analyzed and assessed. Salmon et al. (2010) presented an accompanying method for modeling distributed SA in a system, namely propositional network models. Golightly et al. (2010) explored the concepts and methods of SA and their applicability to the rail domain.

There were two articles related to the measures of SA, including the “Characterisation of mental models in a virtual reality multitasking scenario using measures of SA” from Zhang et al. (2010) and “The role of metacognition in the relationship between objective and subjective measures of SA” from Rousseau et al. (2010). The first paper investigated the relationship between mental models and SA, and the second paper dealt with two measures of SA: QUASA and SART.

The final paper was from Dekker et al. (Situation awareness: some remaining questions; 2010) in which they revealed their misgivings regarding research in the field.

3.3.10 **Stanton, N A., Stewart, R., Harris, D., Houghton, R.J., Baber, C., McMaster, R., Salmon, P.M., Hoyle, G., Walker, G.H., Young, M.S., Linsell, M., Dymott, R., & Green, D. (2006). Distributed situation awareness in dynamic systems: theoretical development and application of an ergonomics methodology. *Ergonomics,* 49(12-13), 1288-1311.**

3.3.11 **Stanton, N.A., Salmon, P.M., Walker, G.H., & Jenkins, D.P. (2010). Is situation awareness all in the mind? *Theoretical Issues in Ergonomics Science*, 11(1-2), 29-40.**

Category: theories/conceptual models; team/shared SA

Keywords: SA; distributed cognition; schema theory; socio-technical systems

The authors reviewed and compared three approaches describing SA, including psychological, engineering and systems ergonomics approaches.

SA as an individual psychological phenomenon is a popular viewpoint in the field of research and practice. The most well known model is the three-level model for individual SA and the related measure method SAGAT proposed by Endsley (1995). The authors in this paper considered that the appeal of the three-level model is that it is both simple to understand and measure. However, the main problem with individual models of human information processing, is they have problems of explaining behaviour outside the unit of analysis for team SA.

Another view of SA is the engineering approach by talking directly to system operators as well as system designers and engineers. Some research has been directed to this approach.

The present authors developed the idea of SA being distributed between the interaction of people with objects in the world, and the Distributed SA (DSA) was presented as an alternative way of thinking about SA at system level, with compatible and transactive features rather than shared.

Based on the results of study on socio-technical systems conducted by Hutchins (1995), the present authors concluded that their DSA model offers the most comprehensive explanation of the phenomena observed in socio-technical systems that offers theoretical framework for aligning the three views of SA.

3.3.12 Wickens, C.D. (2008). Situation Awareness: Review of Mica Endsley's 1995 Articles on Situation Awareness Theory and Measurement. *Human Factors,* 50(3), 397-403.

Category: theories/conceptual models;

Keywords: SA; Endsley's three-level model; review

The author of this paper reviewed two papers about SA and measurement from Endsley (1995), including "Toward a Theory of Situation Awareness in Dynamic Systems" and "Measurement of Situation Awareness in Dynamic Systems."

Based on analysis of Endsley's definition of SA (i.e., "knowing what's going on" or more formally "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 results in the near future"), the author emphasized three phenomena that SA is not: (1) SA is not action or performance; (2) SA is not the same as long-term memory knowledge; and, (3) the product of SA is not the same as the process of updating SA.

The author identified the application areas of SA, including measurement of SA, training, error analysis, design, prediction, teamwork, and automation and workload.

The author concluded that the concept of SA lies at the heart of the intersection between the cognitive psychology and the applied science of human factors. The two articles reviewed here, as well as the vast amount of Endsley's other research, represent a critical contribution within which a growing body of research was integrated and served to stimulate a productive and useful corpus of human factors conclusions and further research.

3.4 Team/Shared SA

Twenty papers were reviewed on the subject of team and shared SA. Rather than repeat summaries of papers, only a reference will be given if a paper has already been covered in earlier theme groups.

3.4.1 **Artman, H., & Garbis, C. (1998). Situation Awareness as Distributed Cognition. In T. Green, L. Bannon, C. Warren, & Buckley (Eds). Cognitive and cooperation. *Proc. of the 9th Conference of Cognitive Ergonomics,* 151-156, Limerick: Ireland J.**

3.4.2 **Bolstad, C.A., Cuevas, H.M., Gonzalez, C., & Schneider, M. (2005). Modeling Shared Situation Awareness. *Proc. of the 14th Conference on Behavior Representation In Modeling and Simulation (BRIMS),* Los Angeles, CA.**

3.4.3 **Bolstad, C.A., Cuevas, H. M., Costello, A.M., & Rousey, J. (2005). *Improving situation awareness through cross training.* Paper Presented at the Human Factors and Ergonomics Society 49th Annual Meeting, Orlando, FL.**

Category: team/shared SA; training

Keywords: cross-training, shared SA, training, SAGAT

This article described an experiment that showed how cross-training might improve shared SA. Cross-training involves training each team member on the duties and tasks of the other team members.

A total of 16 active servicemen and 3 DoD contractors participated in this study. Four individuals had some prior experience working at a military recovery center. Data was collected from the exercise consisted of five different scenarios over a three-day period, in which each participant rotated through the teams and every participant had at least one opportunity to be a team director.

SAGAT was administered at random times throughout the scenarios with seven query questions created based on the fidelity of the exercises and the criticality of certain information requirements identified by the instructors to measure the SA.

The results data from this study provided some initial support for the use of cross-training, particularly in a leadership role, to improve SA. Participants, on average, exhibited greater SA following experience in the director role than prior to director experience.

3.4.4 Endsley, M.R., Jones, W.M. (2001). A Model of Inter- and Intrateam Situation Awareness : Implications for Design, Training, and Measurement. *New trends in cooperative activities: Understanding system dynamics in complex environments,* pp, 46-67. Santa Monica, CA: Human Factors and Ergonomics Society.

Category: team/shared SA; theories/conceptual models; measures of SA

Keywords: team SA, shared SA, interteam SA; team SA requirements, team SA devices, team SA mechanisms, team SA processes, measuring team SA.

This paper described a model of team SA and a model of SA in multiple and distributed teams.

The team SA was defined as “the degree to which every team member possesses the SA required for his or her responsibilities”. A major part of teamwork involves the area in which these SA requirements overlap – the shared SA requirements that exist as a function of the essential interdependency of the team members.

The model of team SA (i.e., intrateam SA) proposed in this article consists of (1) Team SA Requirements; (2) Team SA Devices; (3) Team SA Mechanisms; and, (4) Team SA Processes.

Team SA requirements are essentially a function of their goals and can be specified as the following categories: the data related to system, environment and other team members, the comprehension related to the status of the individual’s and team members’ goals/requirements, the effect of action/changes on each other, and the projection related to actions of team member.

Team SA devices include the method used for achieving shared SA across a team (e.g. direct communication and shared displays, or shared environment).

Team SA mechanisms refer to the shared mental models for high level SA (comprehension and projection), which could be developed through shared training, shared experience and direct communication.

The authors identified the effective team SA processes as self-checking against others at each step, coordinating to get information from each other, prioritizing their goals as a group, and questioning their assumptions and expectations as a group.

The interteam SA was described in similar ways as the single team SA (i.e., interteam SA requirements, interteam SA devices, interteam SA mechanisms and interteam SA processes).

Finally the author suggested that the direct measure approaches may be used to measure team SA (e.g., SAGAT).

3.4.5 **Gonzalez, C., Saner, L., Endsley, M.R., Bolstad, C.A., & Cuevas, H.M. (2009). Modeling and Measuring Situation Awareness in Individuals and Teams. *Proc. of the Advanced decisions architectures for the warfighter: Foundations and technology,* pp, 257-282.**

3.4.6 **Lichacz, F.M.J. (2008). Augmenting understanding of the relationship between situation awareness and confidence using calibration analysis. *Ergonomics*, 51(10), 1489-1502.**

3.4.7 **Nonose, K., Kanno, T., & Furuta, K. (2009). An evaluation method of team situation awareness based on mutual belief. *Cognition, Technology & Work,* 12(1), 31-40.**

Category: team/shared SA; measures of SA

Keywords: team SA; mutual belief; tem coordination; sharedness

This paper described a method for measurement of team SA using mutual belief.

With a brief review, the authors thought that the current observer rating approach made it difficult to understand the cooperative actions of team members. To capture the dynamics and cognitive mechanism behind team cooperation, members' cognitive status should be combined into the definition of team SA.

They then proposed a team cognition model with a three-layer belief structure that captures the intra and inter-personal relation of mental components with mutual beliefs among team members. The first layer represents an individual's cognition with the exception of beliefs; the second layer represents a belief in the partner's cognition; and the third layer represents a belief in the partner's belief.

An experiment with twenty participants (grouped into 10 teams) was conducted to measure team SA using the proposed method. A flight simulator (FALCON 4, Allied Force) was used as the team cooperation task. Subjects were asked to efficiently shoot down enemy aircraft. The sharedness of perception (SA1) and comprehension (SA2) was evaluated by the degree of agreement of certainty of those beliefs. Then, team SA evaluation indexes were developed in terms of both the belief perspective and the observer's perspective.

The results showed that the observer-based team SAs mainly contributed to team performance, however, the belief based indexes also contributed to team performance in some cases.

Finally, the authors proposed that the perspective of belief is effective at capturing the inner state of team cooperation that cannot be captured by the objective team level SA. These two perspectives should be combined so that team level SA and team performance can be evaluated more appropriately.

3.4.8 Patrick, J., James, N., Ahmed, A., & Halliday, P. (2006). Observational assessment of situation awareness, team differences and training implications. *Ergonomics,* 49(4), 393-417.

Category: measures of SA; team/shared SA; training

Keywords: team SA; observational method; rating reliability; training

This paper described a study to investigate two goals, including (1) the practical feasibility and reliability of using an observational methodology to investigate SA with regard to specific events during complex dynamic scenarios, and (2) team SA and aspects that may be problematic in the context of nuclear control room teams.

Five shift teams from one plant took part in three scenarios as part of their bi-annual simulator training. The scenarios consisted of a shift handover with a leak on the main feed pump, a start-up with a partially closed value leading to low flow to a boiler and a bomb explosion and double reactor trip. Each shift completed all three scenarios in 1 day taking between 4.5 and 6.0 hours. The shift's performance for each scenario was video recorded. The reliability was analyzed based on the intraclass correlation coefficient (ICC), and the team SA was analyzed with the Critical Incident Technique.

The authors concluded that this study provided evidence that it is feasible and practicable to utilize observer ratings of SA for specific events when personnel tackle simulated, dynamic scenarios. The important factors that affect team SA include team coordination, planning, problem-solving, attention the pattern of communications and training.

3.4.9 Perla, P.P., Markowitz, M., Nofi, A.A., & Weuve, C. (2000). Gaming and Shared Situation Awareness. *Technical Report of the Centre for Naval Analyses,* pp. 1-74, Alexandria, VA.

Category: team/shared SA; measures of SA

Keywords: computerized simulation, gaming; mental ability; military tactics; modeling and simulation; SA; teams; wargames

This report described a study of team SA in a wargame environment.

The project team devised an experimental design to define both an individual's SA and a team's SA in clear and understandable terms.

They developed an experiment in which multiple teams played an online game with shared information, measurable decisions and sharing.

The testbed game developed was SCUD Hunt, in which each player controlled one or two reconnaissance assets which could provide information about whether a particular square might contain a launcher. Players shared information about the search capabilities of their assets, the results of their searchers and their future search plans. The players' efforts were measured with query-based questionnaires and analyzed with the standard linear statistical model – the Latin Square experimental design with factorial treatments.

The results of the experiment indicated that both communications and shared visualization played statistically significant roles in the ability of their teams to develop shared SA. The results also indicated that voice communications might not be superior to real-time text communications in the experimental context.

3.4.10 **Rousseau, R., Tremblay, S. & Breton, R. (2004). Defining and Modeling Situation Awareness: A Critical Review. In Banbury & S. Tremblay (Eds), *A Cognitive Approach to Situation Awareness: Theory and Application,* pp 3-21. Ashgate: Aldershot.**

3.4.11 **Salas, E., Prince, C., Baker, D.P., & Shrestha, L. (1995). Situation awareness in team performance: Implications for measurement and training. *Human Factors,* 37(1), 123-136.**

Category: team/shared SA; measures of SA; training

Keywords: SA; individual SA; team SA; review

The authors reviewed the processes and behaviours associating with team SA and measurement.

As a component in team SA, the individual SA was summarized first. The authors reviewed several definitions of individual SA. Fracker (1988) defined SA as “the knowledge that results when attention is allocated to a zone of interest at a level of abstraction”. Endsley (1988, 1989, 1990, 1995) defined SA 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”. Tenney et al. (1992) defined SA as both a process and the product of that process.

The authors proposed that team SA involves two critical but poorly understood abstractions: individual SA and team processes. A framework for conceptualizing team SA was presented, which consisted of five components and associations among them: (1) Pre-existing knowledge & pre-dispositions; (2) Task interdependence & team characteristics; (3) Information processing functions; (4) Team process; and, (5) State/goal of team SA

The authors also discussed the measurement and training of team SA. They considered that individual SA and team process are two critical measurements for team SA, and measurements should be made over a series of key events while the team is performing its tasks, with some means such as embedding events in scenarios, rating scales or targeted acceptable responses. Regarding the training of team SA, the authors argued that the training of team SA should focus on complex communication behaviours and team planning, with some means such as feedback, cross-training.

3.4.12 **Salmon, P. M., Stanton, N.A., Walker, G.H., Baber, C., Jenkins, D.P., McMaster, R., & Young, M.S. (2008). What really is going on? Review of situation awareness models for individuals and teams. *Theoretical Issues in Ergonomics Science,* 9(4), 297-323.**

3.4.13 **Salmon, P. M., Stanton, N. A., Walker, G. H., Jenkins, D., Baber, C., & McMaster, R. (2008). Representing situation awareness in collaborative systems: a case study in the energy distribution domain. *Ergonomics,* 51(3), 367-384.**

Category: team/shared SA; theories/conceptual models

Keywords: distributed SA; teamwork; propositional networks; energy distribution

This paper focused on both the theoretical and methodological aspects of SA in collaborative environment.

The authors first reviewed the models of team SA and questioned the utility of current sharedness-based team SA models in real-world collaborative environments. They thought that a recent theory called “Distributed Situation Awareness” (Stanton et al., 2006) could deal with the issues in collaborative environment. The DSA theory treats team SA as a systems level phenomenon and focuses on the overall system itself as the unit of analysis rather than the individuals within it. An approach called propositional network methodology was proposed to represent and analyze the DSA by combining the Critical Decision Method (CDM; Klein and Armstrong, 2005) and the Hierarchical Task Analysis (HTA: Shepherd 1998; Stanton 2006).

The authors described an experiment with the propositional network methodology to analyze the DSA in the UK energy distribution domain. Two scenarios for switching and maintenance were developed to plan, monitor, control and coordinate operations for electricity distribution in a Central Operations Control Room (COCR), in which the COCR operator took on the role of network commander distributing work instructions to the senior authorized persons and authorized persons located at the substations in the field. The analyses were based on data collected during live observational study of the two scenarios.

The authors concluded that the high quality of the networks DSA in the scenarios’ observed was a function of four factors: the efficient communications links between the agents involved; the use of well thought-out and rigidly adhered to procedures; the structure of the network itself; and also the clarity of role definitions.

Based on the results of this study, the authors found that the DSA of the networks adequately supported efficient, timely and safe task performance, since all operations were completed successfully as planned and without incident. The authors concluded that this experiment supports the recently proposed theory of DSA.

3.4.14 Salmon, P.M, Stanton, N.A., Walker, G.H., Jenkins, P, & Rafferty, L. (2010). Is it really better to share? Distributed situation awareness and its implications for collaborative system design. *Theoretical Issues in Ergonomics Science,* 11(1-2), 58-83.

Category: team/shared SA

Keywords: SA; teamwork; propositional networks; distributed cognition; distributed SA

This paper reviewed and clarified the theory of DSA for collaborative environment.

Based on the analysis to existing individual and team SA theories and models, the authors argued that existing prominent individual SA models (e.g., Endsley's three-level model) have a significant problem when such models are applied to collaborative systems because of the dynamic and complex characteristics in collaborative systems. Further, the authors also considered that the existing measurement methods of SA were unsuitable in real-world collaborative environments.

The authors then considered the DSA theory and model to address these concerns. The DSA model (Stanton et al., 2006, 2009) model is underpinned by four theoretical concepts: (1) schema theory (e.g. Bartlett, 1932); (2) genotype and phenotype schema; (3) Neisser's (1976) perceptual cycle model of cognition; and, (4) Hutchins' (1995) distributed cognition approach. This model takes a systems perspective approach to SA and views SA as an emergent property of collaborative systems. The compatible and transactive features are two of the most significant features of the model.

The authors used the propositional network methodology to model the DSA. A propositional network represents information elements and their relationships in DSA, which can be constructed from a variety of data sources, e.g. observational and verbal transcript data, CDM (Klein and Armstrong, 2004) data, HTA (Annet et al., 1971) data or data derived from work-related artefacts.

A case study example was also presented in the paper to examine the DSA model and the feature of compatibility. A land warfare mission planning activity was undertaken using a collaborative process entitled the Combat Estimate. A group of army staff working in the Brigade and Battle Group Headquarters were involved in this study. During the mission planning activities, six analysts undertook direct observation of the activities. Observational transcripts, including verbal protocols, were recorded throughout the activities observed, and then propositional networks were developed. The results in the case study demonstrated the "compatible" feature in DSA.

The authors concluded that the DSA model would be suitable for SA in collaborative systems, however, further investigation was required to understand some limitations in the DSA model.

3.4.15 Saner, L.D., Bolstad, C.A., Gonzalez, C., & Cuevas, H.M. (2009). Measuring and Predicting Shared Situation Awareness in Teams. *Journal of Cognitive Engineering and Decision Making,* 3(3), 280-308.

Category: measures of SA; team/shared SA

Keywords: measures of SA; shared SA

This paper reported a study on the measurement of shared SA on command, control and communications (C3) operations.

Data were collected during a naturalistic study of military personnel engaged in a training exercise at the Joint Personnel Recovery Agency (JPRA), a subsidiary of the U.S. Joint Forces Command (JFCOM) of the U.S. military. Seventeen participants were involved in five personnel recovery simulation scenarios over the course of three days. Based on a demographic questionnaire and a brief description of scenarios, participants were involved in a planning session. SAGAT was used to measure individual SA. Shared SA was measured by a similarity function of SAGAT scores of two participants.

To test which factors were generally predictive of SA and shared SA, they averaged the values on every measure across the time points at which they were measured. Linear regression was used to generate a predictive model with seven predictors, including communication distance, workload similarity, experience similarity, shared knowledge and organizational hub distance.

The results of the study indicated that good shared SA is a matter of both knowledge and coordination, and that neither aspect can be focused on to the exclusion of the other.

The authors concluded that sources of error in SA and methods for correcting it should be a standard topic in discussions of individual and shared SA measurement. The authors also suggested that more studies on dynamic factors involved in team work should be done.

3.4.16 Shu, Y., & Furuta, K. (2005). An inference method of team situation awareness based on mutual awareness. *Cognition, Technology & Work,* 7(4), 272-287.

Category: team/shared SA

Keywords: team SA (TSA); mutual awareness; cooperative activity; TSA inference; team-machine interaction

The authors of this paper proposed a new notion of team SA (TSA), which is reducible to mutual beliefs as well as individual SA at three levels.

They attempted to use precise logical formulation to express the definition of TSA, which specifies a set of heuristic rules. Such rules allow one to reason about TSA, particularly the potential awareness that individuals might have of each other's mental states.

They also developed an operational TSA inference method, which is to identify a set of individual SA and mutual beliefs. Inference of SA and mutual beliefs are parallel mental processes. Both of them are based on a state recognition model by similarity matching and both use domain dependent knowledge stored in the knowledge base.

Based on the proposed TSA model and TSA inference method, a domain independent TSA simulator was developed. Through application of the proposed method to a thermal-hydraulic process simulation, called DURESS, the authors verified that their TSA model reflects cooperative team process more appropriately than the conventional notion of TSA as the intersection of individual SA.

The results showed that verbal communication assumes a very important role in achieving complete and correct TSA. The authors also suggested that the applicability, scalability and advanced stages of human cognition in their model are limited.

3.4.17 **Stanton, N A., Stewart, R., Harris, D., Houghton, R.J., Baber, C., McMaster, R., Salmon, P.M., Hoyle, G., Walker, G.H., Young, M.S., Linsell, M., Dymott, R., & Green, D. (2006). Distributed situation awareness in dynamic systems: theoretical development and application of an ergonomics methodology. *Ergonomics,* 49(12-13), 1288-1311.**

3.4.18 **Strater, L.D., Cuevas, H.M., Connors, E.S., Ungvarsky, D.M., & Endsley, M.R. (2008). Situation Awareness and Collaborative Tool Usage in Ad Hoc Command and Control Teams. *Proc. of the Human Factors and Ergonomics Society 52th Annual Meeting,* 52, 468-472.**

Category: team/shared SA

Keywords: SA; collaborative tool usage; command and control; teams

The authors reported a study to investigate the perceived effectiveness of different collaborative tools in supporting individual and team SA in ad hoc teams.

A total of 86 participants, including two retired Generals, were involved in a Joint Forces C2 operation. A demographic-based questionnaire and a survey of collaborative tools usage were administered. The survey gathered information pertaining to the roles with which they interacted and the effectiveness of the tools they used for both routine and critical communications and to contribute to their SA.

The results showed that the method most preferred for both routine and critical communication was face-to-face interaction. The tool rated most effective for the development of SA changed across study sessions and contexts but included chat and shared map/shared products

3.4.19 Sulistyawati, K., Chui, Y.P., & Wickens, C.D. (2008). Multi-method Approach to Team Situation Awareness. *Proc. of the Human Factors and Ergonomics Society 52nd Annual Meeting,* 52(4), *463*-467, New York, NY.

Category: team/shared SA; measures of SA

Keywords: SA; multi-method; measures of team SA

This paper described a study on team SA assessment with multiple methods including SAGAT and TARGETs.

Sixteen military fighter pilots participated in an air combat game simulated by a PC-based simulation game called Falcon 4.0. Eight pairs (one member as the fight lead and the other member as the wingman) were involved in a group of combat missions designed by two experienced fighter pilots.

A group of assessment methods were used to measure SA, including (1) SAGAT for the SA relevant to own and teammate's responsibilities; (2) confidence bias on the accuracy of SAGAT query responses for the awareness of own SA level; (3) seven-point Likert scales for teammate's workload and SA levels; (4) TARGETs (Targeted Acceptable Responses to Generated Events or Tasks method) for teamwork behavior; and, (5) counting the number of enemy aircraft killed and the number of times shot down by enemy for team performance. Correlation analyses were completed for team SA measures, teamwork behavior and team performance.

The results showed that there were strong associations between team SA and information sharing and backup behavior. SAGAT scores, confidence bias, and backup behavior were also found to have strong associations with team performance.

The authors concluded that team SA is a multi-dimensional construct, and needs to be assessed using multiple methods. Further, the positive associations between some aspects of team SA and teamwork behavior and performance can substantiate the existing theories.

3.4.20 **Wilson, K., Salas, E., Priest, H.A, & Andrews, D. (2007). Errors in the heat of battle: taking a closer look at shared cognition breakdowns through teamwork. *Human factors,* 49(2), 243-256.**

Category: team/shared SA

Keywords: SA; teamwork; taxonomy; shared cognition

The authors of this paper identified and classified teamwork breakdowns as three groups including communication, coordination and cooperation with a human-centered approach to understanding errors leading to fratricide incidents by focusing on shared cognition.

They classified communication as having three sub-groups of factors, including information exchange, phraseology and closed-loop communication, each of which consists of several questions for the breakdowns.

There are four sub-groups of factors involved in the coordination, including knowledge requirements, mutual performance monitoring, backup behaviour and adaptability, with a set of questions in each sub-group.

The cooperation in the classification includes the following four sub-groups: team orientation, collective efficacy, mutual trust and team cohesion.

The authors concluded that this theoretically based framework addressed the observation that poor shared cognition results in teamwork breakdowns.

3.5 SA Measures

Twenty-one papers were reviewed on the subject of SA measures. Rather than repeat summaries of papers, only a reference will be given if a paper has already been covered in earlier theme groups.

3.5.1 **Bell, H., & Lyon, D. 2000). Using Observer Ratings to Assess Situation Awareness. In *Situation Awareness Analysis and Measurement,* 129-146. New York: Lawrence Eribaum.**

Category: measures of SA

Keywords: observational measures, assess SA, subjective measurement, objective measurement, fighter pilots, simulated air combat mission.

This paper described an approach to assess SA (SA) among fighter pilots.

Two experiments were conducted for this approach: one was the measure SA in operational fighter squadrons and another was the measurement SA in simulated air combat missions.

The experimenters developed 4 different rating scales for measuring SA, including the definition of SA, and measurement of SA from self, supervisory, and peer perspectives. SA rating scale data was collected on 238 mission-ready F-15C pilots from 11 squadrons stationed at 4 different Air Force bases. The results showed that the most highly related elements for SA include (1) use of communication information; (2) information integration from multiple sources; (3) time-sharing ability; (4) maintaining track of bogies and friendlies; (5) adjusting the plan on-the-fly; (6) spatial ability to mentally procure engagement; and, (7) lookout for threats from visual, radar warning receiver, & radar.

The second SA measurement was administered in simulated air combat missions to determine the relation between SA and mission performance. They used two F-15C pilots flying high fidelity F-15C simulators for a defensive counter-air mission. The results showed that there was a significant relation between squadron ratings of SA and performance in these simulated air combat missions.

Finally, the authors concluded that both subjective and objective measurement approaches were necessary to develop an understanding of SA. Objective measures are important because they provide a necessary check on subjective judgments. Subjective measures, on the other hand, help to assure that critical aspects of SA are actually being assessed.

3.5.2 Endsley, M.R. (1995). Measurement of Situation awareness in dynamic systems. *Human Factors,* 37(1), 65-84.

Category: measures of SA

Keywords: methods of measurement of SA, freeze technique, SAGAT

The author, based on a review of various methods for the empirical measurement of SA, described a query-based freeze technique for the measurement of SA with two example studies.

This paper first categorized the physiological methods of measurement of SA (electroencephalograph, eye tracking), the performance measures (global measures, external task measures, imbedded task measures), the subjective techniques (self-rating, observer-rating), and the questionnaires (post-test, on-line, freeze technique). It reviewed each method in the categories and discussed the advantages, disadvantages, and the potential limitations of the measures from a theoretical and practical viewpoint.

Based on the review, the author proposed a freeze technique to measure SA, whereby each task is randomly frozen and a set of SA queries regarding the current situation is administered. The participants are required to answer each query based upon their knowledge of the situation at the point of the freeze. SAGAT was the computerized freeze technique that was developed to assess pilot SA across the three levels of SA proposed by the author (i.e. perception of the elements, comprehension of their meaning and projection of future status) for the aviation domain.

This paper described two studies that investigated questions of validity and intrusiveness regarding the query-based technique. The studies found that subjects were able to report their SA using this technique without apparent memory decay, and the freeze did not appear to be intrusive on subject performance in the simulation, allaying sever concerns about the technique.

The author made several recommendations for using SAGAT including training of subjects, test design, procedures, questions, and data collection.

3.5.3 Endsley, M.R. (1995). Direct Measurement of Situation Awareness in Simulations of Dynamic Systems : Validity and Use of SAGAT. *Proc. of the International Conference on Experimental Analysis and Measurement of Situation Awareness,* Daytona Beach, FL.

Category: Measures of SA

Keywords: SAGAT, impact of SAGAT data collection

This study explored the intrusiveness of the freeze technique for the measurement of SA (i.e. whether operator performance is affected by merely the threat of a stop) to collect SAGAT data.

A set of 90 trials was conducted during an air-to-air fighter sweep mission with six experienced former military fighter pilots. These trials included mixed stop/non-stop trials, told and untold stops.

The results of this study confirm previous findings and did not find a demonstrable performance effect as a results of freezes in a simulation.

This paper also contained a section for several recommendations for SAGAT administration (e.g. training of subjects, test design, procedures, queries, time of SAGAT data collection, and number of trials).

3.5.4 **Endsley, M.R., Holder, L.D., Leibrecht, B.C., Garland, D.J., Wampler, R.L., & Matthews, M.D. (1999). *Modeling and Measuring Situation Awareness in the Infantry Operational Environment.* Unpublished report.**

3.5.5 **Endsley, M.R., Sollenberger, R., & Stein, E. (2000). Situation Awareness: A Comparison of Measures. *Proc. of the Human Performance, Situation Awareness and Automation: User Centered Design for the New Millennium Conference*, Savannah, GA.**

Category: measures of SA

Keywords: SA, SAGAT, SART, air traffic control, measurement of SA, comparison of SA measurement methods

This paper compared the different measures of SA in a study related to Air Traffic Control (ATC).

Ten experienced controllers with an average of 15.4 years of experience in ATC, eight men and two women, were included in the study for helping maintain self-separation operation of aircraft. The test was conducted using the ATCoach Version 7.0 simulation system.

Four measurement methods of SA were examined including the SAGAT, the On-line Probe similar to the Situation Present Assessment Method (SPAM), SART, and the Subjective Measure of SA.

The study found that the SART and the on-line probes did not show a significant difference between conditions. However, the SAGAT scores were sensitive to the display manipulation in this study. In particular it provided a clear indication of the SA support that was provided by the enhanced display which provided good diagnosticity. The one-line probes were not found to be correlated with SAGAT, but were weakly correlated with workload. Observer ratings of SA were found to be highly related to observer ratings of performance.

3.5.6 **Endsley, M.R., Jones, W.M. (2001). A Model of Inter- and Intrateam Situation Awareness : Implications for Design, Training, and Measurement. *New trends in cooperative activities: Understanding system dynamics in complex environments,* pp, 46-67. Santa Monica, CA: Human Factors and Ergonomics Society.**

3.5.7 **Gonzalez, C., Saner, L., Endsley, M.R., Bolstad, C.A., & Cuevas, H.M. (2009). Modeling and Measuring Situation Awareness in Individuals and Teams. *Proc. of the Advanced decisions architectures for the warfighter: Foundations and technology,* pp, 257-282.**

3.5.8 **Jones, D.G., & Endsley, M.R. (2000). Can Real-Time Probes Provide a Valid Measure of Situation Awareness? *Proc. of the Human Performance, Situation Awareness and Automation: User Centered Design for the New Millennium Conference*, Savannah, GA.**

Category: measures of SA

Keywords: SA, real-time probes, SAGAT, SART, measurement

This paper examined the validity of the real-time probes method for measures of SA.

Based on the simulators at an air force base, two 60-minute scenarios related to all aspects of the air sovereignty team were developed, one with a low to moderate level of workload (peace) and the other with a moderate to high level workload (war). Five teams participated in the study, including experienced technicians and commanders. During the experiment, real-time probes, SAGAT, SART, and workload were collected. ANOVAs and regressions were used to analyze the sensitivity and validity of real-time probes as compared with other measures.

The results were concluded as follows: All three SA measures including the real-time probes, SAGAT and SART showed sensitivity to differences between the war and peace scenarios. A weak but significant correlation was found between real-time probes and SAGAT. The authors thought that, based on the results, increasing the number of real-time probes might provide increased sensitivity. Based on the assessment of the relation between real-time probes and workload, although the evidence supports the hypothesis that the real-time probes are a measure of SA rather than workload, a weak correlation was found between the real-time probes and the NASA-Task Load Index (TLX) scores (a workload survey).

The author recommended that (1) the number of probes needs to be increased to acquire the needed sensitivity; and, (2) a minimal number of probes should include only the most crucial information which supports the design and conduct of a repeated measures design; and, (3) real-time probes have the potential to provide an adequate measure of SA in the case where no simulation facility exists and the activity cannot be temporarily halted.

3.5.9 **Kirlik, A., & Strauss, R. (2006). Situation awareness as judgment I: Statistical modeling and quantitative measurement. *International Journal of Industrial Ergonomics.* 36(5), 463-474.**

3.5.10 **Lichacz, F.M.J. (2008). Augmenting understanding of the relationship between situation awareness and confidence using calibration analysis. *Ergonomics*, 51(10), 1489-1502.**

3.5.11 **McGuinness, B. (2004). Quantitative Analysis of Situational Awareness (QUASA) : Applying Signal Detection Theory to True/False Probes and Self-Ratings. *Proc. of the 9-th International Command and Control Research and Technology Symposium,* Copenhagen, Demark.**

3.5.12 **Nonose, K., Kanno, T., & Furuta, K. (2009). An evaluation method of team situation awareness based on mutual belief. *Cognition, Technology & Work,* 12(1), 31-40.**

3.5.13 **Patrick, J., James, N., Ahmed, A., & Halliday, P. (2006). Observational assessment of situation awareness, team differences and training implications. *Ergonomics,* 49(4), 393-417.**

3.5.14 **Perla, P.P., Markowitz, M., Nofi, A.A., & Weuve, C. (2000). Gaming and Shared Situation Awareness. *Technical Report of the Centre for Naval Analyses,* pp. 1-74, Alexandria, VA.**

3.5.15 **Rousseau, R., Tremblay, S., Banbury, S., Breton, R., & Guitouni, A. (2010). The role of metacognition in the relationship between objective and subjective measures of situation awareness. *Theoretical Issues in Ergonomics Science,* 11(1-2), 119-130.**

3.5.16 **Salas, E., Prince, C., Baker, D.P., & Shrestha, L. (1995). Situation awareness in team performance: Implications for measurement and training. *Human Factors,* 37(1), 123-136.**

3.5.17 **Salmon, P.M., Stanton, N.A., Walker, G.H., & Green, D. (2006). Situation Awareness Measurement: A review of applicability for C4i environments. *Applied Ergonomics,* 37(2), 225-238.**

3.5.18 Salmon, P.M., Stanton, N.A., Walker, G.H., Jenkins, D., Ladva, D., Rafferty, L., & Young, M. (2009). Measuring Situation Awareness in complex systems: Comparison of measures study. *International Journal of Industrial Ergonomics,* 39(3), 490-500.

Category: measures of SA

Keywords: SA; SA measurement; C2

This article described an experiment that used a military planning task to compare two different SA measures including the freeze probe (i.e., SAGAT) and the subjective rating approach (i.e., SART).

Twenty participants, acting in the role of Commanders, were asked to undertake a Military Operations in Urban Terrain (MOUT) warfare scenario. The SAGAT probes were used during the scenario and upon completion of the experimental trials; the SART questionnaire and the NASA TLX workload questionnaire were completed. Mean scores and correlations were analyzed.

The results indicated that only the participant SA scores derived via the freeze probe recall method produced a statistically significant correlation with performance on the planning task and also that there was no significant correlation between the SAGAT and SART methods. This finding suggests that the tools were measuring different aspects of participant SA during the trials.

The authors concluded that while raising doubts over the validity of the post trial subjective rating approach, the study offered validation evidence for the use of freeze probe recall approaches to measure SA during simulated tasks.

3.5.19 **Saner, L.D., Bolstad, C.A., Gonzalez, C., & Cuevas, H.M. (2009). Measuring and Predicting Shared Situation Awareness in Teams. *Journal of Cognitive Engineering and Decision Making,* 3(3), 280-308.**

3.5.20 **Strauss, R., & Kirlik, A. (2006). Situation awareness as judgment II: Experimental demonstration. *International Journal of Industrial Ergonomics,* 36(5), 475-484.**

3.5.21 **Tremblay, S., Jeuniaux, P., Romano, P., Lowe, J., & Grenier, R. (2010). A Multi-Perspective Approach to the Evaluation of a Portable Situation Awareness Support System in a Simulated Infantry Operation. *Proc. of the IEEE First International Multi-Disciplinary Conference on Cognitive Methods in Situation Awareness and Decision Support (CogSIMA 2010),* pp. 119-122.**

Category: measures of SA; perspective/approaches

Keywords: SA; portable support system; augmented cognition; cognitive system engineering

The authors in this article proposed a systematic and innovative approach to the design of Portable SA Support System (P-SASS) that combined the use of human and computer agent simulation, non-intrusive objective metrics and cognitive system engineering to assess the benefits of such systems to the tactical commander.

Six CF SMEs participated in a simulated scenario and measurement of performance pertaining to in military operations. First, this study compared the use of the P-SASS prototype developed by THALES with the traditional map and radio. The objective event-based measures of performance during the simulation and the objective offline measures of SA (QUASA) after the simulation then were taken. Finally, the traditional subjective measures of usability were gathered at the end of the study and analyzed in combination with the objective measurements.

The results in this study showed that (1) the P-SASS increased awareness of positioning; (2) participants' confidence in their own SA was well calibrated when using the system; and, (3) responsiveness seemed to benefit from the use of the P-SASS.

The authors concluded that the study provided insights into the current design process by pointing out the situations in which the P-SASS was the most helpful and highlighting the features which should be incorporated in future prototypes.

3.6 SA Training

Seven papers were reviewed on the subject of SA training. Rather than repeat summaries of papers, only a reference will be given if a paper has already been covered in earlier theme groups.

3.6.1 **Bolstad, C.A., Cuevas, H. M., Costello, A.M., & Rousey, J. (2005). *Improving situation awareness through cross training.* Paper Presented at the Human Factors and Ergonomics Society 49th Annual Meeting, Orlando, FL.**

3.6.2 **Gonzalez, C., & Wimisberg, J. (2007). Situation Awareness in Dynamic Decision Making: Effects of Practice and Working Memory. *Journal of Cognitive Engineering and Decision Making,* 1(1), 56-74.**

3.6.3 **Kass, S.J., Herschler, D.A., & Companion, M.A. (1991). Training situational awareness through pattern recognition in a battlefield environment. *Military Psychology,* 3(2), 105-112.**

Category: training SA

Keywords: training SA, pattern recognition

This paper described an experiment to determine whether training strategy could enhance acquisition of the pattern recognition skill associated with the interpretation of muzzle-flash patterns.

Twenty civilian volunteers participated in the study. Two SIMNET M1A1 tank simulations were employed in this study, which included tanks, artillery, trucks, and other features representative of a normal battlefield environment. Elliptically shaped tank-muzzle flashes were presented to subjects and were consistent throughout the training and testing condition. Subjects in the experimental condition were trained with a minimum of extraneous cues. Data were collected during test trials in which participants in both groups had the same visual scene, and were analyzed with using an ANOVA.

The authors concluded that the pattern identification training was successful (i.e., subjects performed better in simulated battlefield conditions following training in an environment that contained only the cues necessary for pattern identification skill acquisition). This finding fully supports the hypothesis and the principles of skill-based SA.

3.6.4 **O'Brien, K.S., & O'Hare, D. (2007). Situational awareness ability and cognitive skills training in a complex real-world task. *Ergonomics*, 50(7), 1064-91.**

3.6.5 **Patrick, J., James, N., Ahmed, A., & Halliday, P. (2006). Observational assessment of situation awareness, team differences and training implications. *Ergonomics,* 49(4), 393-417.**

3.6.6 **Salas, E., Prince, C., Baker, D.P., & Shrestha, L. (1995). Situation awareness in team performance: Implications for measurement and training. *Human Factors,* 37(1), 123-136.**

3.6.7 **Strater, L.D., & Bolstad, C.A. (2008). Simulation-Based Situation Awareness Training. In D.A. Vincenzi, J.A. Wise, M. Mouloua & P.A. Hancock (Eds), *Human factors in simulation and training,* pp. 129-148. New York: Lawrence Eribaum Associates.**

Category: training of SA

Keywords: SA; simulation; training of SA

The authors in this paper proposed a structured SA-oriented training development process with six steps.

- Step 1: Identify domain-specific SA requirements with various methods including expert elicitation, direct observation of domain tasks, analysis of manuals and checklists, and CTA;
- Step 2: Identify and develop SA measures with the existing methods, including process indices, indirect behavioral and performance measures, and direct subjective and objective measures;
- Step 3: Identify SA deficits within the domain with a variety of techniques, such as identifying differences between good and poor SA, analyzing existing research and training data, surveys, and analysis of SA errors within the domain;
- Step 4: Develop training programs to target selected skills by pattern matching and improved schemata and mental models;
- Step 5: Validate training programs employing measures that are sensitive to changes in the diverse parameters that comprise SA; and,
- Step 6: Identify training modifications needed to improve SA.

The authors concluded that the SA-oriented training development process described in this paper is well suited to guide training designers to select skill areas to provide the most benefit to the end users.

4 CONCLUSIONS

Overall 58 papers were reviewed for this annotated bibliography. While not exhaustive, these papers represent the leading contributors and SA that have been published in the last 20 years. The most papers reviewed concerned team or shared SA, and measurement of SA, reflecting the most recent research emphasis in the topic area. The number of papers also reflects a broader acceptance of the concept and a willingness to apply its tenets to more complex systems (as measured by the number of human operators interacting with each other directly and through intermediary systems).

The papers include good representation from Endsley who is first author on 9 papers and is a co-author on 4 further papers. Endsley's traditional collaborators are also well represented. In recent years, however, the publications of a group of British researchers have been progressing the science of SA. In particular the works of Salmon (6 papers as first author and a further 3 as a co-author) and Stanton (4 papers as first author and a further 6 as a co-author) merit closer reading.

As far as possible, the content of the papers is relevant to the consideration of SA in any situation, not only in some specific application context. The papers speak to the underlying theory of SA and approaches to using it in applied situations, such as design or performance measurement. The review also included papers that disagree with the notion of SA, believing these counterpoints to be an essential part of the understanding of the topic.

5 REFERENCES

Artman, H., & Garbis, C. (1998). Situation Awareness as Distributed Cognition. In T. Green, L. Bannon, C. Warren, & Buckley (Eds). Cognitive and cooperation. *Proc. of the 9th Conference of Cognitive Ergonomics,* 151-156, Limerick: Ireland.

Banbury, S. and Tremblay, S. (2004). A cognitive approach to situation awareness: Theory and application. Ashgate Publishing, Aldershot, England.

Bedny, G., & Meister, D. (1999). Theory of activity and situation awareness. *International Journal of Cognitive Ergonomics,* 3(1), 63-72.

Bell, H., & Lyon, D. 2000). Using Observer Ratings to Assess Situation Awareness. In *Situation Awareness Analysis and Measurement,* 129-146. New York: Lawrence Eribaum.

Bolstad, C.A, Riley, J.M, Jones, D.G, & Endsley, M.R. (2002). Using Goal Directed Task Analysis with Army Brigade Officer Teams. *Proc. of the 46-th Annual Meeting of the HFES conference,* pp, 472-476, Santa Monica, CA.

Bolstad, C.A., Cuevas, H. M., Costello, A.M., & Rousey, J. (2005). *Improving situation awareness through cross training.* Paper Presented at the Human Factors and Ergonomics Society 49th Annual Meeting, Orlando, FL.

Bolstad, C.A., Cuevas, H.M., Connors, E.S., Gonzalez, C., Foltz, P.W., Lau, N.K.C., & Warwick, W.J. (2010). Advances in Modeling Situation Awareness, Decision Making, and Performance in Complex Operational Environments. *Proc. of the HFES conference,* pp, 1047-1051, Santa Monica, CA.

Bolstad, C.A., Cuevas, H.M., Gonzalez, C., & Schneider, M. (2005). Modeling Shared Situation Awareness. *Proc. of the 14th Conference on Behavior Representation In Modeling and Simulation (BRIMS),* Los Angeles, CA.

Dekker, S.W. A., Hummerdal, D.H., & Smith, K. (2010). Situation awareness: some remaining questions. *Theoretical Issues in Ergonomics Science,* 11(1-2), 131-135. London: Taylor & Francis.

Endsley, M.R. (1988). Design and evaluation for situation awareness enhancement. Paper presented at the Human Factors and Ergonomics Society 32nd Annual Meeting, pp. 97-101), Santa Monica, CA.

Endsley, M.R. (1995a). Direct Measurement of Situation Awareness in Simulations of Dynamic Systems : Validity and Use of SAGAT. *Proc. of the International Conference on Experimental Analysis and Measurement of Situation Awareness,* Daytona Beach, FL.

Endsley, M.R. (1995b). Measurement of Situation awareness in dynamic systems. *Human Factors,* 37(1), 65-84.

Endsley, M.R. (1995c). Toward a Theory of Situation Awareness in Dynamic Systems. *Human factors.* 37(1), 32-64.

Endsley, M.R. (2000a). Situation Models: An Avenue to the Modeling of Mental Models. *Proc. of the 44-th Annual Meeting of the HFES Conference,* pp, 61-64, Santa Monica, CA.

Endsley, M.R. (2000b). Theoretical Underpinnings of Situation Awareness: A Critical Review. In *Situation Awareness Analysis and Measurement,* 1-24. Mahwah, NJ: LEA.

Endsley, M.R. (2001). Designing for Situation Awareness in Complex System. Proc. of the Second international workshop on symbiosis of humans, artifacts and environment, Kyoto, Japan.

Endsley, M.R., Holder, L.D., Leibrecht, B.C., Garland, D.J., Wampler, R.L., & Matthews, M.D. (1999). *Modeling and Measuring Situation Awareness in the Infantry Operational Environment.* Unpublished report.

Endsley, M.R., Jones, W.M. (2001). A Model of Inter- and Intrateam Situation Awareness : Implications for Design, Training, and Measurement. *New trends in cooperative activities: Understanding system dynamics in complex environments,* pp, 46-67. Santa Monica, CA: Human Factors and Ergonomics Society.

Endsley, M.R., Sollenberger, R., & Stein, E. (2000). Situation Awareness: A Comparison of Measures. Proc. of the Human Performance, Situation Awareness and Automation: User Centered Design for the New Millennium Conference, Savannah, GA.

Flach, J.M. (1995). Situation Awareness: Proceed with Caution. *Human Factors,* 37(1), 149-157.

Gonzalez, C., & Wimisberg, J. (2007). Situation Awareness in Dynamic Decision Making: Effects of Practice and Working Memory. *Journal of Cognitive Engineering and Decision Making,* 1(1), 56-74.

Gonzalez, C., Saner, L., Endsley, M.R., Bolstad, C.A., & Cuevas, H.M. (2009). Modeling and Measuring Situation Awareness in Individuals and Teams. *Proc. of the Advanced decisions architectures for the warfighter: Foundations and technology,* pp, 257-282.

Hourizi, R., & Johnson, P. (2003). Towards an explanatory, predictive account of awareness. *Computers & Graphics,* 27(6), 859-872.

Johannsdottir, K.R. and Herdman, C.M. (2010). The role of working memory in supporting drivers' situation awareness for surrounding traffic. *Human Factors,* 52(6), 663-673.

Jones, D.G., & Endsley, M.R. (2000). Can Real-Time Probes Provide a Valid Measure of Situation Awareness? *Proc. of the Human Performance, Situation Awareness and Automation: User Centered Design for the New Millennium Conference*, Savannah, GA.

Kass, S.J., Herschler, D.A., & Companion, M.A. (1991). Training situational awareness through pattern recognition in a battlefield environment. *Military Psychology,* 3(2), 105-112.

Kirlik, A., & Strauss, R. (2006). Situation awareness as judgment I: Statistical modeling and quantitative measurement. *International Journal of Industrial Ergonomics.* 36(5), 463-474.

Lichacz, F.M.J. (2008). Augmenting understanding of the relationship between situation awareness and confidence using calibration analysis. *Ergonomics*, 51(10), 1489-1502.

McGuinness, B. (2004). Quantitative Analysis of Situational Awareness (QUASA) : Applying Signal Detection Theory to True/False Probes and Self-Ratings. *Proc. of the 9-th International Command and Control Research and Technology Symposium,* Copenhagen, Demark.

Nonose, K., Kanno, T., & Furuta, K. (2009). An evaluation method of team situation awareness based on mutual belief. *Cognition, Technology & Work,* 12(1), 31-40.

Ntuen, C.A. (2006). The Knowledge Structure of the Commander in Asymmetric Battlefield: The Six Sights and Sensemaking Process. *Proc. of the 12-th International Command & Control Research and Technology Symposium (CCRTS)*, San Diego, CA.

O'Brien, K.S., & O'Hare, D. (2007). Situational awareness ability and cognitive skills training in a complex real-world task. *Ergonomics*, 50(7), 1064-91.

Patrick, J., James, N., Ahmed, A., & Halliday, P. (2006). Observational assessment of situation awareness, team differences and training implications. *Ergonomics,* 49(4), 393-417.

Perla, P.P., Markowitz, M., Nofi, A.A., & Weuve, C. (2000). Gaming and Shared Situation Awareness. *Technical Report of the Centre for Naval Analyses,* pp. 1-74, Alexandria, VA.

Rousseau, R., Tremblay, S. & Breton, R. (2004). Defining and Modeling Situation Awareness: A Critical Review. In Banbury & S. Tremblay (Eds), *A Cognitive Approach to Situation Awareness: Theory and Application,* pp 3-21. Ashgate: Aldershot.

Rousseau, Robert, Tremblay, Sébastien, Banbury, Simon, Breton, Richard, Guitouni, Adel. (2010). The role of metacognition in the relationship between objective and subjective measures of situation awareness. *Theoretical Issues in Ergonomics Science,* 11(1-2):119-130.

Salas, E., Prince, C., Baker, D.P., & Shrestha, L. (1995). Situation awareness in team performance: Implications for measurement and training. *Human Factors,* 37(1), 123-136.

Salmon, P. M., Stanton, N. A., Walker, G. H., Jenkins, D., Baber, C., & McMaster, R. (2008). Representing situation awareness in collaborative systems: a case study in the energy distribution domain. *Ergonomics,* 51(3), 367-384.

Salmon, P. M., Stanton, N.A., Walker, G.H., Baber, C., Jenkins, D.P., McMaster, R., & Young, M.S. (2008). What really is going on? Review of situation awareness models for individuals and teams. *Theoretical Issues in Ergonomics Science,* 9(4), 297-323.

Salmon, P.M, Stanton, N.A., Walker, G.H., Jenkins, P, & Rafferty, L. (2010). Is it really better to share? Distributed situation awareness and its implications for collaborative system design. *Theoretical Issues in Ergonomics Science,* 11(1-2), 58-83.

Salmon, P.M., Stanton, N.A., & Young, K.L. (2011). Situation awareness on the road: review, theoretical and methodological issues, and future directions. *Theoretical Issues in Ergonomics Science,* May 2011, 1-21.

Salmon, P.M., Stanton, N.A., Walker, G.H., & Green, D. (2006). Situation Awareness Measurement: A review of applicability for C4i environments. *Applied Ergonomics,* 37(2), 225-238.

Salmon, P.M., Stanton, N.A., Walker, G.H., Jenkins, D., Ladva, D., Rafferty, L., & Young, M. (2009). Measuring Situation Awareness in complex systems: Comparison of measures study. *International Journal of Industrial Ergonomics,* 39(3), 490-500.

Saner, L.D., Bolstad, C.A., Gonzalez, C., & Cuevas, H.M. (2009). Measuring and Predicting Shared Situation Awareness in Teams. *Journal of Cognitive Engineering and Decision Making,* 3(3), 280-308.

Sharma, S., & Ivancevic, V.G. (2010). Nonlinear dynamical characteristics of situation awareness. *Theoretical Issues in Ergonomics Science*, 11(5), 448-460.

Shu, Y., & Furuta, K. (2005). An inference method of team situation awareness based on mutual awareness. *Cognition, Technology & Work,* 7(4), 272-287.

Smith, K., & Hancock, P.A. (1995). Situation Awareness Is Adaptive, Externally Directed Consciousness. *Human Factors,* 37(1), 137-148.

Soliman, A.M. (2010). Exploring the central executive in situation awareness. *Psychological Reports,* 106(1), 105-118.

Stanton, N A., Stewart, R., Harris, D., Houghton, R.J., Baber, C., McMaster, R., Salmon, P.M., Hoyle, G., Walker, G.H., Young, M.S., Linsell, M., Dymott, R., & Green, D. (2006). Distributed situation awareness in dynamic systems: theoretical development and application of an ergonomics methodology. *Ergonomics,* 49(12-13), 1288-1311.

Stanton, N.A. (2010). Situation awareness: where have we been, where are we now and where are we going? *Theoretical Issues in Ergonomics Science,* 11(1-2), 1-6.

Stanton, N.A., Salmon, P,M., Walker, G,H., & Jenkins, D. (2009). Genotype and phenotype schemata and their role in distributed situation awareness in collaborative systems. *Theoretical Issues in Ergonomics Science*, 10(1), 43-68.

Stanton, N.A., Salmon, P.M., Walker, G.H., & Jenkins, D.P. (2010). Is situation awareness all in the mind? *Theoretical Issues in Ergonomics Science*, 11(1-2), 29-40.

Strater, L.D., & Bolstad, C.A. (2008). Simulation-Based Situation Awareness Training. In D.A. Vincenzi, J.A. Wise, M. Mouloua & P.A. Hancock (Eds), *Human factors in simulation and training,* pp. 129-148. New York: Lawrence Eribaum Associates.

Strater, L.D., Cuevas, H.M., Connors, E.S., Ungvarsky, D.M., & Endsley, M.R. (2008). Situation Awareness and Collaborative Tool Usage in Ad Hoc Command and Control Teams. *Proc. of the Human Factors and Ergonomics Society 52th Annual Meeting,* 52, 468-472.

Strauss, R., & Kirlik, A. (2006). Situation awareness as judgment II: Experimental demonstration. *International Journal of Industrial Ergonomics,* 36(5), 475-484.

Sulistyawati, K., Chui, Y.P., & Wickens, C.D. (2008). Multi-method Approach to Team Situation Awareness. *Proc. of the Human Factors and Ergonomics Society 52nd Annual Meeting,* 52(4), *463*-467, New York, NY.

Sulistyawati, K., Wickens, C.D., & Chui, Y.P. (2011). Prediction in Situation Awareness: Confidence Bias and Underlying Cognitive Abilities. *The International Journal of Aviation Psychology,* 21(2), 153-174.

Tremblay, S., Jeuniaux, P., Romano, P., Lowe, J., & Grenier, R. (2010). A Multi-Perspective Approach to the Evaluation of a Portable Situation Awareness Support System in a Simulated Infantry Operation. *Proc. of the IEEE First International Multi-Disciplinary Conference on Cognitive Methods in Situation Awareness and Decision Support (CogSIMA 2010),* pp. 119-122.

Wickens, C.D. (2008). Situation Awareness: Review of Mica Endsley's 1995 Articles on Situation Awareness Theory and Measurement. *Human Factors,* 50(3), 397-403.

Wilson, K., Salas, E., Priest, H.A, & Andrews, D. (2007). Errors in the heat of battle: taking a closer look at shared cognition breakdowns through teamwork. *Human factors,* 49(2), 243-256.

DOCUMENT CONTROL DATA

(Security classification of the title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATOR (The name and address of the organization preparing the document, Organizations for whom the document was prepared, e.g. Centre sponsoring a contractor's document, or tasking agency, are entered in section 8.)

Publishing: DRDC Toronto

Performing: CAE Professional Services Inc., Ottawa, ON K2K 3G7

Monitoring:

Contracting:

2. SECURITY CLASSIFICATION (Overall security classification of the document including special warning terms if applicable.)

UNCLASSIFIED
(NON-CONTROLLED GOODS)
DMC A
REVIEW: GCEC JUNE 2010

3. TITLE (The complete document title as indicated on the title page. Its classification is indicated by the appropriate abbreviation (S, C, R, or U) in parenthesis at the end of the title)

Situation Awareness: Annotated Bibliography (U)
(U)

4. AUTHORS (First name, middle initial and last name. If military, show rank, e.g. Maj. John E. Doe.)

Guo, J.

5. DATE OF PUBLICATION (Month and year of publication of document.)	6a NO. OF PAGES (Total containing information, including Annexes, Appendices, etc.)	6b. NO. OF REFS (Total cited in document.)
March 2012	79	60

7. DESCRIPTIVE NOTES (The category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of document, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

Contract Report

8. SPONSORING ACTIVITY (The names of the department project office or laboratory sponsoring the research and development - include address.)

Sponsoring:

Tasking:

9a. PROJECT OR GRANT NO. (If appropriate, the applicable research and development project or grant under which the document was written. Please specify whether project or grant.)	9b. CONTRACT NO. (If appropriate, the applicable number under which the document was written.)
14cg01	W7711-088140/001/TOR

10a. ORIGINATOR'S DOCUMENT NUMBER (The official document number by which the document is identified by the originating activity. This number must be unique to this document)	10b. OTHER DOCUMENT NO(s). (Any other numbers under which may be assigned this document either by the originator or by the sponsor.)
DRDC Toronto CR 2012-115	

11. DOCUMENT AVAILABILITY (Any limitations on the dissemination of the document, other than those imposed by security classification.)

Unlimited distribution

12. DOCUMENT ANNOUNCEMENT (Any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11), However, when further distribution (beyond the audience specified in (11) is possible, a wider announcement audience may be selected.))

Unlimited announcement

DOCUMENT CONTROL DATA

(Security classification of the title, body of abstract and indexing annotation must be entered when the overall document is classified)

13. ABSTRACT (A brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), (R), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual.)

(U) A review of the theoretical literature concerning Situation Awareness (SA) was undertaken, covering the following six theme groups; SA and Cognitive Processes; SA Theories/Conceptual Models; SA Perspectives/Approaches; Team/Shared SA; SA Measures; and, SA Training. A total of 58 papers were reviewed for this contract. For each paper a summary is provided along with the bibliographic details in American Psychology Association (APA) format. This review will assist Defence Research and Development Canada (DRDC) to focus their efforts to support the Primary Leadership Qualification (PLQ) curriculum by highlighting the important and informative papers on SA.

(U) Une analyse de la documentation théorique portant sur la connaissance de la situation (CS) a été entreprise, et portait sur les six thèmes suivants : la CS et les processus cognitifs; les théories et les modèles conceptuels relatifs à la CS; les perspectives et les approches liées à la CS; la CS en équipe ou partagée; les mesures de la CS, et la formation en matière de CS. En tout, 58 documents ont été analysés dans le cadre de ce contrat. Pour chacun d™eux, un sommaire est fourni ainsi que les détails bibliographiques sous le format prévu par l™American Psychology Association (APA). La présente analyse aidera Recherche et développement pour la défense Canada (RDDC) à axer ses efforts sur le soutien à apporter au programme de Qualification élémentaire en leadership (QUEL), en soulignant les documents importants et informatifs sur la CS.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

(U) awareness, SA, shared SA, team SA, cognitive processes, conceptual models, team training, team theory, team measures, team metrics, annotated bibliography