State-of-the-science review of Situation Awareness Models

Stanton, N. A.[1*], Salmon, P. M.[2] and Walker, G. H.[3]

Affiliations
[1]Transportation Research Group, Civil, Maritime, Environmental Engineering and Science, Faculty of Engineering and the Environment, Boldrewood Innovation Campus, University of Southampton, Burgess Road, Southampton, SO16 7QF, UK

[*]Corresponding author: n.stanton@soton.ac.uk

[2]Centre for Human Factors and Sociotechnical Systems, Faculty of Arts and Business, University of the Sunshine Coast, 4558, Queensland, Australia

Centre for Sustainable Road Freight Heriot-Watt University, Edinburgh, EH14 4ES, UK

Abstract: This review paper takes one of the most controversial topics in Ergonomics, namely situation awareness, and presents the three key sets of models. These models are split into individual SA, team SA and systems SA typologies. Despite, or perhaps because of, the controversy, SA has remained an enduring theme for research and practice in the domain of Ergonomics over the past two decades. Whilst it is not possible to resolve the controversies and differences between the positions, it is possible to show mediation via a contingent approach to problem-model matching. This is fundamental to Ergonomics theory, matching the models and methods appropriately to the problem domain being faced.

Keywords: Situation awareness, theory, models, individual SA, team SA, system SA, distributed SA

THE STATE OF THE SCIENCE

Situation awareness (SA) is one of the most keenly studied topics in Ergonomics (Wickens, 2008; Salmon and Stanton, 2013; Stanton et al, 2010) and also one of its most controversial. The term is used to describe how people, and increasingly entire socio-technical systems, become and remain coupled to the dynamics of their environment (Moray, 2004). As a concept it provides researchers and practitioners with various models and methods to either describe what SA comprises, to determine how individuals, teams or systems develop SA, or to assess the quality of SA during task performance (Salmon and Stanton, 2013). It should also provide explanations for what happens when SA is lost, and how it affects performance when it is gained (Stanton et al, 2015).

Unusually for an Ergonomics concept it has entered the mainstream lexicon and is used in many contexts and professions to refer interchangeably to information that resides in people's heads, minds (Fracker 1991, Sarter and Woods 1991, Endsley 1995) or even brains (Endsley, 2015); as something which exists in the world, in displays or other environmental features (e.g. Ackerman, 1998, 2005); as something which is an emergent property of people and their environment (Stanton et al. 2006, 2009a, 2010); or as a form of distributed cognition (e.g. Hutchins, 1995a & b). SA has been explored in many areas, ranging from military settings (e.g. Endlsey 1993; Salmon et al, 2009; Stanton et al, 2006; Stanton, 2014; Stewart et al, 2008), transportation (e.g. Ma & Kaber, 2007; Golightly et al, 2010, 2015; Salmon et al, 2014, Walker et al, 2008, 2009) sport (Bourboussan et al, 2011; James & Patrick, 2004; Macquet & Stanton, 2014; Neville and Salmon, 2016), health care and medicine (Bleakley et al, 2013; Fioratou et al, 2010; Hazlehurst, McCullen & Gorman, 2007; Schulz, 2013), process control (Salmon et al, 2008; Sneddon et al, 2015; Stanton et al, 2009b) and the emergency services (Seppanen et al, 2015; Blandford and Wong, 2005). The papers that deal with the concept are among the most top cited in the discipline (e.g. Lee, Cassano-Pinche´ & Vicente, 2005) and the term SA is one of the most widely used (Patrick & Morgan, 2010). A cursory glance at GoogleNgram (Figure 1) shows that the term situation awareness was hardly used at all within the corpus of English language literature prior to Endsley's (1988),Woods (1988) and other pioneering publications on SA in the late 80's, with the line graph accelerating dramatically from that point forward. Despite its prevalent use in many areas our understanding of SA is still in development (Flach, 1995; Dekker, 2015). Indeed, in such a fast moving and important part of the discipline, a state-of-the-science review is not merely timely, it is probably over-due.

Figure 1 – Google Ngram plot showing how the use of the term Situation Awareness in the English language lexicon has accelerated dramatically since the 1980s

Like so many other Ergonomics concepts, such as workload (Young et al, 2015), trust (Kauer et al, 2015), mental models (Revell and Stanton, 2012), and safety (Hignett et al, 2013) there is no universally accepted definition of situation awareness. There are definitions that are more popular than others, but there are clear differences in how some researchers and practitioners understand and define the concept. Unlike workload, trust and mental models, and as starkly illustrated in recent special issues on SA, the topic is unusual for how hotly debated it is (see Carsten and Vanderhaegen, 2015; Endsley, 2015; Salmon et al, 2015; Stanton, 2010, 2016;

Stanton et al, 2015). Providing that positions do not become too entrenched, for everyone else in the profession this debate creates a rich and exciting eco-system of ideas around SA theory (Stanton, 2016) and methods (Salmon and Stanton, 2013).

So what, exactly, are the key issues? Taken at face value the discipline has a dominant theory of SA (the three level model put forward by Endsley in a special issue of Human Factors in 1995 is undoubtedly the most popular) and associated methods with which to convert it into ergonomic practice (of which there are lots of examples). If we define the discipline purely in terms of a pragmatic philosophy, and judge success only in terms of practical application, then a state of science review will be exceedingly short and uninspiring. Thankfully, this is not the case. What makes the state of science in SA so captivating is how radically different the concept of SA looks when projected through different world-views. What is becoming increasingly evident is that the worldview through which early models of SA were projected is quite different from the world-view that exists today. When Endsley's first paper on SA was published in the 1988 proceedings of the US Human Factors and Ergonomics Society Annual meeting, the dominant paradigm of experimental and cognitive psychology was very much in the ascendency within the discipline, something van Winsen and Dekker (2015) refer to as the 'first cognitive revolution'. Ideas around systems thinking, specifically distributed cognition (e.g. Hutchins, 1995a, b) and cognitive systems engineering (Rassmussen et al, 1994) were far from mainstream and in many cases in their infancy. Compare this situation with today, when there is a much stronger systems focus (Salmon et al, 2015; Dul, et al., 2012) and a growing recognition of the importance that systems concepts like complexity (Walker et al., 2010), constraints (Vicente, 1999), dynamism (Dekker & Woods, 2000), multiplicity (Lee, 2001), fuzziness (Karwowski 2000, Lee et al. 2003), randomness (Hancock, et al. 2000) and the myriad other terms used to describe the kinds of problems Ergonomist are called upon to help resolve. Nearly thirty years since the term situational awareness entered the Human Factors lexicon the paradigm has shifted, with the second cognitive (systems) revolution upon us (van Winsen & Dekker, 2015).

The goal of this state of science review, therefore, is to convey the richness of the debate around SA, to project the concept through different world views, try to understand where the contention comes from, how it can be resolved, and its important ramifications for the benefactors of the services Ergonomists dispense. We argue it is not sufficient to judge any important ergonomic concept purely on the criterion of practical expediency. To continue to advance the state-of-science in this review we need to go further.

DEFINING SITUATION AWARENESS

At the most basic level, avoiding for the moment any strong links to a particular paradigm, situational awareness could be described simply as the ability of actors (usually humans, but not necessarily) to become and remain coupled to the dynamics of their environment (e.g. Woods, 1988; Moray, 2004). This is on the assumption that being coupled to the dynamics of an environment is a desirable state of affairs for behaviours occurring within that environment (but again, not necessarily). In other words, "knowing what is going on around you" or "having the big picture" (Jones, 2015, p. 98).

These high-level definitions of SA exhibit a strong 'situation focus'. They rely on the notion of information, that is, items or artifacts in the situation about which individuals require awareness in order to act effectively (Baber, 2004; Endsley, 1988). Further, it requires a "mapping of the relevant information in the situation onto a mental representation of that information within the [individual]" (Rousseau, Tremblay & Breton, 2004, p. 5). The term 'mental representation' reflects two aspects of 'awareness'. Firstly, that information elements are structured and that SA is not merely about the presence or absence of discrete elements but also their interconnection. Billings (1995) talks of an "abstraction within our minds" which reflects a second aspect of awareness, that it is hypothetical in nature (Bryant et al., 2004). 'Awareness' of a situation by an individual is not a canonical model (e.g. Banbury, Croft, Macken & Jones, 2004), rather, it is "a representation that mirrors, duplicates, imitates or in some way illustrates a pattern of relationships observed in data or in nature […]", "a characterisation of a process […]" (Reber, 1995, p.465). In some form or other SA needs to provide individuals with "explanations for all attendant facts" (Reber, 1995; p. 793) in order for them to make better decisions and benefit from improved performance. A key issues is that explanations for attendant facts do not necessarily require a particularly rich or detailed model of the situation. Indeed, it would be a highly inefficient representation if it did, and one not likely to have been supported by several millennia of human evolution. On the contrary, there is robust evidence (e.g. Gobet, 1998; Chase & Simon, 1973) that the better the mental representation (or awareness), the more parsimonious it is; the more parsimonious, the more that the 'information in working memory' upon which awareness is based (e.g. Bell & Lyon, 2000) is forced into higher, more implicit levels of abstraction (Walker et al, 2009). In terms of the situation focus, then, the paradox is that the better a person (or 'agent's') 'mental theory' of their situation the 'less' likely it is to have a direct one-to-one mapping to the object or situation that is being perceived.

High-level definitions of SA also carry with them a certain linear or sequential flavour. Many models of SA, including the most dominant (e.g. Endsley, 1995), assume that "humans typically operate in a closed-loop manner" (Endsley, 1995, p. 33). Whilst there can be little doubt that human performance does indeed rely on a cycle of input-processing-output-feedback, this does not need tobe the case all the time. There are many examples from the psychological and human factors literature where a larger proportion of behaviour than is often acknowledged is feed-forward (Plant and Stanton, 2013). Tasks such as driving, for example, which are routine and well-learned can often be performed on the basis of well-developed mental theories that require minimal input to guide effective behavior (Stanton et al, 2007; Walker et al., 2009c). Consider, for example, the concept of Driving Without Attention (May & Gale, 1998) or mode errors in which 'knowledge in the head' (awareness) overrides 'knowledge in the world' (the actual situation: see Stanton & Walker, 2011).

As well as linearity and sequence, high-level definitions of SA also carry with them a ‘normative’ flavour, the tacit assumption being that the objective situation provides a reference point for judging ‘goodness’ or ‘badness’ of SA (Endsley, 1988, p. 793). SA, however, is created for a purpose (Patrick & James, 2004) and that purpose is to generate better situations to be aware of. Smith and Hancock (1995) put it that SA can be viewed as “a generative process of knowledge creation” (p. 142) in which “[…] the environment informs the agent, modifying its knowledge. Knowledge directs the agent’s activity in the environment. That activity samples and perhaps anticipates or alters the environment, which in turn informs the agent” (Smith & Hancock, 1995, p. 142) and so on in a cyclical manner. Smith and Hancock refer to SA as ‘constructive’, which is to say the agent or actor is a part of the situation they find themselves in and can influence its dynamics. In other words, they are not a passive observer, rather, they are an agent in an interactive system (Stanton and Walker, 2011; Plant and Stanton, 2012). Clearly, SA is more complex than the everyday usage of the term might suggest.

THE PROBLEM DOMAINS

The definition of SA has changed and developed over the past 25 years, reflecting a change in foci of the Ergonomics discipline as well as the facets of SA. Early definitions of SA focused on the individual person, as defined by Endsley:

“Situational awareness 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” (Endsley, 1988).

As research interest in SA grew, so it expanded from individuals to teams. Definitions of SA came to reflect this also:

“the shared understanding of a situation among team members at one point in time” (Salas et al., 1995, p. 131)

Contemporary research into Systems Ergonomics has led to an interest in applying SA across socio-technical systems. Again this has led to new definitions, such as:

“activated knowledge for a specific task within a system….[and] the use of appropriate knowledge (held by individuals, captured by devices, etc.) which relates to the state of the environment and the changes as the situation develops” (Stanton et al, 2006, p. 1291).

In aviation, for example, one could study the awareness of individual pilots, specifically the pilot flying. Or it could be expanded to include the aircrew, not just the pilot flying but the captain, engineer/navigator, cabin or cargo crew. The analysis could also include the flight deck instruments, flight deck computer, flight director, autopilot, air traffic management system, flight data recorders, and so on

(Stanton et al, 2010; Sorensen et al, 2011). After all, these system agents (i.e. both human and non-human entities) also have to be aware of their situation in order to function as they should, or at the very least, help human agents to do so. It is possible to go even further than this, to consider the wider system of agents and actors within which the aircraft is operating: the air traffic management and control personnel and systems, tower control, ground control, ground staff, flight operations staff, other aircraft, even much higher level entities such as organisations and entire infrastructures. From a linear, sequential and normative perspective on SA this might seem controversial, yet these factors are present in recent disasters such as Air France 447 (Salmon et al, 2016). Here the aeroplane and cockpit systems were not aware of the current airspeeds. Following the autopilot's disconnection in response to this, the aircrew were then unaware of why the autopilot had disconnected, the key flight parameters that led to the disconnection, and the control inputs needed to create a better situation. Added to this is that each of flight phases represent different 'situations' for the system as a whole, but within these, the situation is changing dynamically, moment-by-moment, for each of the individual agents. So not only is consideration of human and non-human agent awareness becoming increasingly important given technological advances such as artificial intelligence and advanced automation, but so too is the notion of multiple 'agents' cooperating over time in order to remain coupled to the dynamics of their environment. Issues like these lie at the heart of Socio-Technical Systems (STS) approaches (Walker et al, 2009). From this perspective, rather than simply defining the characteristics of individual elements and seeking to combine these, one has to study the system at the appropriate level, be it individuals, teams or entire systems. We will use this idea of levels of analysis to frame the SA theories and methods in the following sections.

THEORETICAL MODELS OF SA

In the previous section three distinct types of SA models were identified: individuals, teams and systems. The theoretical bases for these models are further explored in this section.

Models accounting for situation awareness held by individuals

Early models of SA focussed on individual operators and how they cognitively acquired SA during task performance (e.g. Adams, Tenney & Pew, 1995; Bedney and Miester, 1999; Endsley, 1995; Smith & Hancock, 1995). Heavily psychology-based, these models attempted to explain the processes underpinning the awareness held in the minds of individual operators, that is, SA as experienced in the mind the person (Stanton et al, 2010; Endsley, 2015). This focus incorporates the psychological processes involved (e.g. mental models, schema, perception, comprehension) and the nature of SA itself (e.g. the person's SA comprises knowledge about x, y, and z). Two of these models in particular stand out in the literature (Wickens, 2008), one being by far the most popular, the other receiving increasing attention as individual models begin to be integrated with systems models (e.g. Stanton et al, 2009a, b). Both are shown, with others, in Table 1.

Table 1 - Theories that account for Situation Awareness held by Individuals

Definition	**Author**	**Theoretical Underpinning**	**Origin**	**Google Scholar Citation**
Perception of elements, comprehension of meaning and projection of future status	Endsley (1988)	Three-level model	Started with aviation, later spread to other domains	2253
Situation awareness is adaptive, externally-directed consciousness that has its products knowledge about a dynamic task environment and directed action within that environment.	Smith & Hancock (1995)	Perceptual cycle model	Air traffic control	204
Situation awareness is based on the integration of knowledge resulting from recurrent situation assessments.	Sarter & Woods (1991)	Working memory, mental models, situation assessment awareness	Aviation	273
"…an abstraction that exists within our minds, describing phenomena that we observe in humans performing work in a rich and usually dynamic environment."	Billings (1995)	Information processing theory	Aviation	31
Situation awareness is knowledge of current and near term disposition of both enemy and friendly forces within a volume of airspace.	Hamilton (1987)	Three-level model	Military airspace	6
SA contributed to good performance, it is not synonymous with it. It is possible to have good SA but still not be a good pilot because of poor motor skills, coordination or attitude problems. Conversely, under automated flight conditions it is possible to have good performance with minimal SA.	Adams, Tenney & Pew (1995)	Perceptual cycle model, working memory	Aviation	33
SA is the pre-requisite state of knowledge for making adaptive decisions in situations involving uncertainty, i.e. a veridical model of reality.	Taylor (1990)	Theories of attention and cognition	Military, air traffic control and nuclear power	272

Endsley's three-level model (1995a) has undoubtedly received the most attention with almost 2249 citations recorded for the original paper in the Scopus database (Scopus, 15th February 2016). This establishes it as the most cited paper on SA and indeed one of the most cited Ergonomics papers of all time. The information processing-based model describes SA as an internally held cognitive product comprising three levels: perception (level 1), comprehension (level 2) and projection (level 3), which feeds into decision-making and action execution. Level 1 SA involves perceiving the status, attributes and dynamics of task-related elements in the surrounding environment (Endsley, 1995). According to the model a range of factors influence the data perceived, including the task being performed, the individual's goals, experience, expectations and also systemic factors such as interface design, level of complexity and automation. To achieve Level 2 SA, the individual interprets the level 1 data and comprehends its relevance to their task and goals. Level 3 SA involves forecasting future system states using a combination of level 1 and 2 SA-related knowledge, and experience in the form of mental models. By these means individuals can forecast likely future states and use this to take action.

Endsley's model foregrounds cognitive models of information processing, and evidence of this can be seen in the loose parallels that can be drawn between more basic Input-Processing-Output models of cognition (Stanton et al, 2001). Endsley's model is of course more complex and nuanced than this, but the hereditary line is apparent and entirely consistent with the zeitgeist of cognitive psychology evident at the theory's inception in the 1980's. Smith and Hancock's (1995) ecological approach to SA is different and offers a useful contrast. It is based on schema theory (Plant and Stanton, 2013), in particular Neisser's (1976) perceptual cycle model. On these terms, Smith and Hancock describe SA as a:

'generative process of knowledge creation and informed action taking' (1995, p. 138).

Neisser's model describes the cyclical nature of perception and actions, showing how our interaction with the world is directed by internally held schemata or mental templates, and in turn how the outcome of our interactions then serves to modify the initial schemata, which in turn directs further interactions. Using this model, Smith and Hancock (1995) argued that SA is a sub-set of working memory but, more importantly, that it neither resides exclusively in the world nor exclusively in the person, but instead arises through the interaction of the person with the world. This is an important point of departure. Smith & Hancock (1995) describe SA as 'externally, directed consciousness' that is an 'invariant component in an adaptive cycle of knowledge, action and information' (p. 138). It is argued that the process of achieving and maintaining SA revolves around internally held schema, which contain information regarding certain situations. These schema facilitate the anticipation of situational events, directing an individual's attention to cues in the environment and directing their eventual course of action. An individual then conducts checks to confirm that the evolving situation conforms to their expectations. Any unexpected events serve as a prompt for further search and explanation, which in turn modifies the operators existing model.

Models based on the notion that SA resides in the minds of individuals provide some satisfactory answers to certain types of problem. They provide a ready explanation for how SA works in some situations, and practical methods to enable SA of this type to be captured in an expedient way. They provide less satisfactory answers for other types of SA issue. They tend not to acknowledge that good SA should help the actor to create a better situation to be aware of, that knowledge in the head (or expectancy) can enable actors to create a rich awareness of their situation from very limited external stimuli, and that normative performance standards against which to judge the 'rightness' of SA do not exist in many tasks, and may in fact be undesirable. These fundamental limitations in the individualistic/cognitive approach to SA can be distilled into a set of tacit assumptions about SA itself; that it is static and normative. This is not to suggest such models are not effective in certain practical situations, but it is important to acknowledge that in applying individualistic versions of SA certain assumptions are being made. It is fair to say that if the part of the socio-technical system under analysis can be usefully regarded as stable, normative, closed loop and deterministic, then stable, normative, closed loop and deterministic approaches are entirely appropriate. Many practical problems do indeed take this form (e.g. highly scripted tasks in which deviations from normative performance standards are not desired such as a pilot conducting pre-flight checks with checklists), but not all. From this has emerged the need for other researchers to project SA through different lenses, including teams and systems.

Models accounting for situation awareness held by teams

The problem spaces in which Ergonomics researchers and practitioners operate are frequently characterised by the presence of teams (Annett and Stanton, 2000). Teams are defined as "a distinguishable set of two or more people who interact dynamically, interdependently and adaptively toward a common and valued goal, who have each been assigned specific roles or functions to perform and who have a limited life span of membership" (Salas, Prince, Baker and Shrestha, 1995). Salas (2004) suggests that the characteristics of teams include meaningful task interdependency, co-ordination among team members, specialised member roles and responsibilities, and intensive communication. It is not surprising, then, that researchers quickly began to examine SA in team environments (Endsley, 1993; Salas et al, 1995; Shu and Furuta, 2005; Wellens, 1993; Table 2).

Table 2 - Definitions accounting for Situational Awareness held by Teams

Theory	Domain of Origin	Applications	Authors	Theoretical Underpinning	Google Scholar Citation
Team SA	Aviation	Military aviation maintenance	Endsley & Robertson (2000)	Three-level model	100
Inter- and intra-team SA	Military	Military	Endsley & Jones (2001)	Three-level model	140
Team SA	Generic	None	Salas et al. (1995)	Three-level model, team work theory	482
Team SA	Military	Military	Wellens (1983)	Three-level model, distributed decision-making model	144

Many early team SA applications involved scaling Endsley's model up to the team level, incorporating the related concepts of team SA (the degree to which every team member possesses the SA required for his or her responsibilities; Endsley, 1989) and shared SA (the degree to which team members have the same SA on shared SA requirements; Endsley and Jones, 1997). Using the three level model as its basis, this approach to team SA argues that that team members have distinct portions of SA, but also overlapping or 'shared' portions of SA. Successful team performance requires that individual team members have good SA on their specific elements and the same SA for shared SA elements (Endsley and Robertson, 2000).

As above, while this approach provides satisfactory answers to some types of team SA questions it is less satisfactory for others (Stanton et al, 2001). As a result, two team SA models have received particular attention in the literature: Salas et al's (1995) team SA model, and Shu and Furuta's (2005) mutual awareness model. Salas et al. (1995) argued that team SA comprises individual SA and various team processes. The critical component of team SA, according to Salas et al, is communication. They argue that the perception of SA elements is influenced by the communication of mission objectives, individual tasks and roles, team capability and other team performance factors. Salas et al. (1995) further argued that schema limitations can be offset by information exchange afforded by communication and coordination between team members. The comprehension of this information is affected by the interpretations made by other team members, so it is evident that SA leads to SA and also modifies SA. In other words, individual SA is developed and then shared with other team members, which then develops and modifies team member SA. Thus a cyclical process of developing individual SA, sharing SA with other team members and then modifying SA based on other team members SA is apparent. This again is another point of departure. Salas et al. (1995) conclude that team SA 'occurs as a consequence of an interaction of an individual's pre-existing relevant knowledge and expectations; the information available from the environment; and cognitive processing skills that include attention allocation, perception, data extraction, comprehension and projection' (Salas et al., p. 125).

Shu and Furuta (2005) expanded team SA models by proposing the concept of mutual awareness, which is conceptually similar to Endsley's shared SA. They argue that team SA comprises both individual SA and mutual awareness. This is the mutual understanding of each other's activities, beliefs and intentions (Shu and Furuta, 2005). They further describe how team SA is a partly shared and partly distributed understanding of a situation among team members. For example, in the cockpit, mutual awareness would be achieved when both the pilot flying and the pilot not flying are able to understand each other's behaviours and motives when dealing with an in-flight problem. Shu and Furuta (2005) defined team SA as, 'two or more individuals share the common environment, up- to-the-moment understanding of situation of the environment, and another person's interaction with the cooperative task.' (Shu and Furuta, 2005, p. 274).

Models based on the notion that team SA relies on a combination of individual and shared awareness also reveal some fundamental limitations in the cognitive/experimental psychology approach. This time it is the idea that shared SA is equivalent to identical SA, and once again, while the notion of teams admits the possibility of greater degrees of change and dynamism, the normative nature of SA tends to remain. As above, this is not to suggest that such models are not effective in practical situations, but it is again important to acknowledge that in applying several of the most popular team-SA approaches certain assumptions are being made. Upon closer inspection they provide less than satisfactory answers to some forms of practical problem.

Models accounting for situation awareness held by sociotechnical systems

For a concept that began in the world of cognitive psychology SA is no different to the Ergonomics discipline more generally. The paradigm is shifting, however, and the strategic direction of the discipline is anchored firmly to increasing extents of systems thinking (e.g. Dul et al., 2014; Walker et al, 2010; Walker, 2016). A distinct part of the 'ergonomic offer' to stakeholders, therefore, is its role within systems and SA is naturally an important part of this.

Systems thinking presents some distinct challenges for SA. Socio-Technical Systems (STS) describe a combination of people ('socio') with technical systems that interact so as to support some organisational activity. Typically it involves many stakeholders (with different goals) and is governed by organisational policies, rules and culture, and may be affected by external constraints such as national laws and regulatory policies. A cornerstone of the STS concept is that interacting combinations of people and systems are non-deterministic, but in a desirable way. It is about designing systems such that advantageous 'jointly optimised' behaviours emerge from low level processes, of which one is undoubtedly SA. STSs are inherently complex, with this complexity particularly manifest in high-technology and safety-critical domains (i.e. aviation, aerospace, nuclear power, chemical and petroleum process industries and defence). In all these domains, and many more besides, close coupling and interactive complexity leads to unexpected ways for systems to fail (Stanton and Walker, 2011; Salmon et al, 2013; Perrow, 2001). Whilst it is self-evident that that the complexity of STSs, comprising many agents, elements, subsystems and their interconnections it is less obvious that such systems are non-reductive. In other words, it is not easy to disaggregate complex systems into smaller units as one could with more traditional linear systems (Walker et al, 2010). This reductionistic approach has been the cornerstone of the ergonomics' discipline's roots in experimental cognitive psychology, offering both an explanation for SA's roots in similarly reductionist modes of thought, but also a challenge for increasingly systemic ways of thinking (van Winsen & Dekker, 2015). A list of theories that try to account for systemic SA is shown in table 3.

Table 3 – Theories that account for Situation Awareness as a Systems Phenomenon

Theory	Domain of Origin	Applications	Authors	Theoretical Underpinning	Google Scholar Citation
Distributed cognition approach	Tele-operation	Tele-operations	Artman & Garbis (1998)	Distributed cognition theory	120
Military awareness team SA model	Process control Artificial intelligence	Process control	Shu & Furuta (2005)	Three level model , shared cooperative activity theory (Bratman, 1992)	74
Distributed SA model	Maritime	Military, maritime, energy distribution, aviation, air traffic control, emergency services, road and rail transport	Stanton et. al (2006)	Perceptual cycle (Neisser, 1976) Distributed cognition theory (Hutchins, 1995) Distributed SA theory (Artman & Garbis, 1995)	239

SA was first discussed at a systems level by Artman & Garbis (1998) who called for a systems perspective SA. It is also a theme picked up on by Shu and Furuta (2005), albeit one that attempts to enhance the individualistic three level model via cooperative activity theory (Bratman, 1992). Stanton et al's (2006) model is perhaps the closest the discipline currently has to a systems view of SA, to the extent that the 'system view' in question is most firmly couched in systems theory. It is underpinned by three theoretical concepts: schema theory (e.g. Bartlett, 1932 – both genotype and phenotype schema), Neisser's (1976) perceptual cycle model of cognition and, of course, Hutchin's (1995b) distributed cognition approach. In this model SA is viewed as an emergent property of collaborative systems, arising from the interactions between agents, both human and technological. According to Stanton et al (2006; 2009a, b) a system's awareness comprises a network of information on which different components of the system have distinct views and ownership of information. Scaling the model down to individual team members brings Neisser's perceptual cycle, as it was originally envisaged, into more clear focus, showing where in the cycle individuals are and what is happening as they traverse it (Neisser, 1976). At the individual and team levels, people possess specific genotype schema that are developed during task performance by task relevant features; during task performance, the more generic phenotype schema comes to the fore (Plant and Stanton, 2014, 2015). It is through this task and schema driven process that the notion of shared SA (e.g. Endsley & Robertson, 2000) into question. This is because rather than possess shared SA (which suggests team members understand a situation or elements of a situation in the same manner) the model instead suggests team members possess unique, but compatible, types of awareness. Team members experience a situation in different ways as defined by their own personal experience, goals, roles, tasks, training, skills, schema and so on. Compatible awareness is what holds distributed systems like these together (Stanton et al, 2006; 2009a, b; Stanton, 2014). Each team member has their own awareness, related to the goals that they are working toward. This is not the same as other team members, but is such that it enables them to work with adjacent team members. Although different team members may have access to the same information, differences in goals, roles, the tasks being performed, experience and their schema mean that their resultant awareness of it is not shared. It is different yet compatible, and collectively required so that the system as a whole can perform the collaborative task taking place within it.

The compatible SA view does not discount the sharing of information, nor does it discount the notion that different team members have access to the same information; this is where the concept of SA 'transactions' applies (Sorensen and Stanton, 2015). Transactive SA describes the notion that DSA is acquired and maintained through transactions in awareness that arise from communications and sharing of information. A transaction in this case represents an exchange of SA between one agent and another (where agent refers to humans and artefacts). As agents receive information, it is integrated with other information and acted on, and then passed onto other agents. The interpretation on that information changes per team member. For example, when ATM provides instruction to an aircraft in a particular phase of flight, the resultant transaction in SA for each pilot is different, depending on their role (pilot flying or pilot monitoring). Each pilot is using the information for their own ends, integrated into their own schemata, and reaching an individual interpretation. An exchange rather than a sharing of awareness. Transactive SA elements from one model of a situation can form an interacting part of another without any necessary requirement for parity of meaning or purpose; it is the systemic transformation of situational elements as they cross the system boundary from one team member to another that bestows upon system SA an emergent behaviour. Flowing from this theory are a set of tenets that serve as a lens through which future systems SA concepts can be critiqued or indeed the tenets themselves modified (Stanton et al, 2006; Stanton, 2016):

1. Situation awareness is an emergent property of sociotechnical systems. Accordingly, the system represents the unit of analysis, rather than the individual agents working within it;
2. Situation awareness is distributed across the human and non-human agents working within the system;
3. Systems have a dynamic network of information upon which different operators have their own unique view of, and contribution to; somewhat akin to a "hive mind" (Seeley et al, 2012). The compatibility between these views is critical to support safe and efficient performance, with incompatibilities creating threats to performance, safety and resilience;
4. Systemic SA is maintained via transactions in awareness between agents. These exchanges in awareness can be human to human, human to artefact, and/or artefact to artefact and serve to maintain, expand, or degrade the network underpinning the awareness within it;
5. Compatible SA is required for systems to function effectively: rather than have shared awareness, agents have their own unique view on the situation which connect together to form systemic SA; and
6. Genotype and phenotype schema play a key role in both transactions and compatibility of SA.

The DSA approach is one of a small number of systems SA approaches. It has been useful to show some of the differences that emerge when SA is projected through a systems lens. In representing a point of radical departure from some other approaches it has been a good exemplar (Stanton et al, 2015; Salmon et al, 2015).

One final but important question needs to be asked. Is the concept of SA useful? Does it result in improved performance? The assumption throughout this review is that yes, it is useful. There is growing evidence form laboratory studies that using SA principles results in improved performance. Indeed, in a recent review of the field, Wickens (2008) present a strong case for the value that SA has to offer the science of Ergonomics, and the number of citations and the use of the term in everyday language attests to that. Interestingly, however, the relationship between SA and task performance was initially difficult to prove (Endsley, 1995). It is unquestionably the case that good task performance can occur despite poor SA and vice versa, so clearly the relationship is more complex than a simple one to one SA/task performance mapping. Current but research is providing the much needed evidence and insights (Griffin et al, 2010; Sorensen and Stanton, 2013; Sorensen and Stanton, 2016; Rafferty et al., 2013; Walker et al, 2009). These studies suggest that DSA is not only a useful concept but it is also correlated to task success or failure. Different models of SA are also useful, but perhaps in different circumstances and for different reasons.

CONCLUSIONS FOR THE FUTURE OF SA

Recent debates in the literature have tended to be somewhat adversarial, with the perceived merits of one approach being compared with the perceived demerits of another (Endsley 2015; Salmon et al, 2015; Stanton et al, 2015). This approach can be useful to drive out valid points of issue and subject theories and concepts to a stress test. Beyond that is a more measured picture, indeed, one that goes to the heart of wider methodological issues in Ergonomics. Simply put there is no one best theory, rather, it depends on the fundamental nature of the problem to which different SA approaches are being applied (Stanton et al, 2010). All have a role to play. If the practical SA issue being examined can be reasonably characterized as stable, relying on deviations from accepted normative practices, and focusing on individual personnel, then there are SA theories which match perfectly to this situation and will deliver the insights needed. If, on the other hand, the problem can be characterized by a sociotechnical system in which SA is neither normative or stable, and resides as a systems phenomenon rather than individual one, then likewise, other approaches matched to these features will deliver the needed insights. This is summed up diagrammatically in Figure 2. The key issue is that an overly doctrinaire and rigid approach, not flexible to the nature of the problems being tackled, will a) fail to deliver the required insights and/or b) do so with excessive analytical effort compared to alternatives and/or c) in the worst case retard understanding and diminish the reputation of the discipline.

To end on a positive note is to say that the future is bright for SA research and practice. Systems continue to become more complex and technology-driven, which in turn raises important questions around awareness and how best to support it across individuals, teams, organisations, and entire systems. In addition, critical new SA research questions continue to reveal themselves, such as how human operators can exchange awareness with artificial intelligence, how we can study SA in teams comprised entirely of non-human agents, and how to design advanced automation systems where awareness is distributed (e.g. vehicle to vehicle and vehicle to infrastructure road transport environments). The concept’s popularity is such that it continues to be applied in new domains and there is no doubt new questions will arise, and new areas to be explored. The challenges and opportunities for SA are limitless.

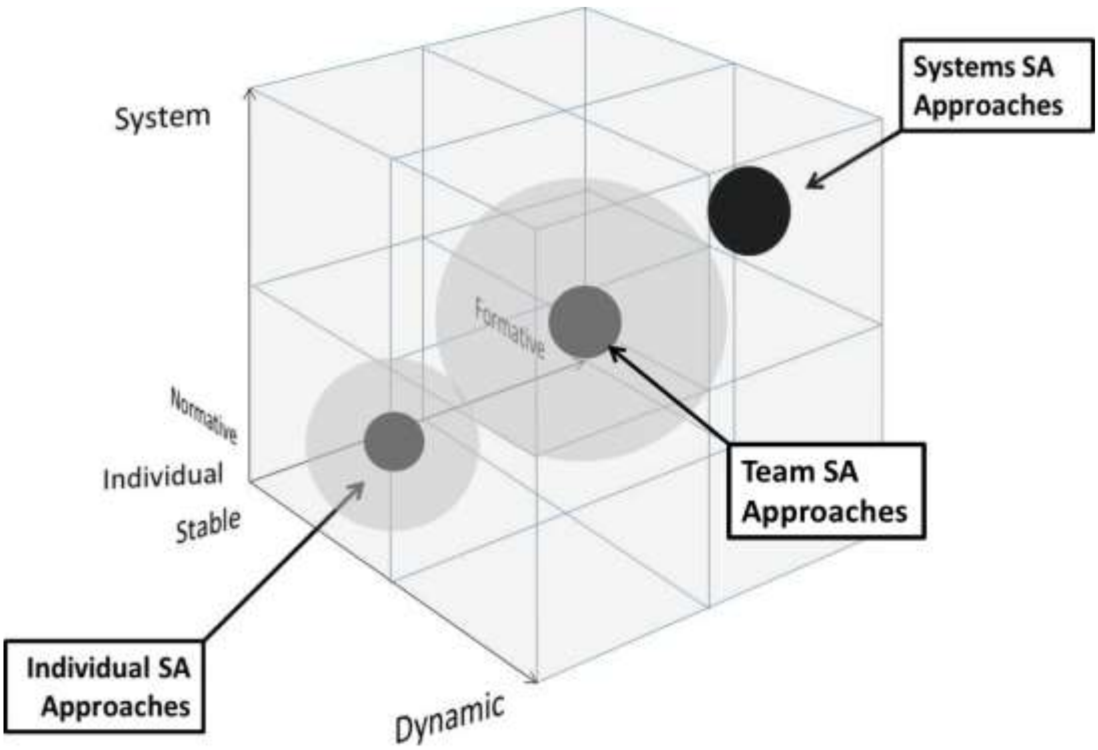

Figure 2 – Different approaches to SA match to different features of ergonomic problems. By its nature, the more systemic the SA model the more of the problem space it can operate within, although other approaches may prove more practically expedient. The real challenge going forward is to become better at this matching rather than compete one approach with another.

REFERENCES

ACKERMAN, R.K., 1998. New display advances brighten situational awareness picture. Combat Edge[online]. Available from: https://www.highbeam.com/doc/1P3-33041082.html [Accessed 19 February 2013].

ACKERMAN, R.K., 2005. Army intelligence digitizes situational awareness. Signal [online]. Available from: http://sncorp.com/[Accessed 19 February 2015].

ADAMS et al 1995. SA special issue of Human Factors

ANNETT, J. & STANTON, N. A. (2000) Team work: A problem for Ergonomics? Ergonomics, 43, 1045-1051.

ARTMAN, H., & GARBIS, C. (1998). Situation awareness as distributed cognition.

BABER, C. (2004). Personal communication.

BANBURY, S. P., CROFT, D. G., MACKEN, W. J. & JONES, D. M. (2004). A cognitive streaming account of situation awareness. In S. Banbury & S. Tremblay (Eds) A cognitive approach to situation awareness: theory and application. (Ashgate: Aldershot).

BARTLETT, F. 1932. Remembering.

BEDNY, G. and MEISTER, D., 1999, Theory of activity and situation awareness. *International Journal of Cognitive Ergonomics*, 3(1), pp. 63–72.

BELL, H.H and LYON, D.R., 2000, Using observer ratings to assess situation awareness. In Situation Awareness Analysis and Measurement, M.R. Endsley (Ed.) (Mahwah, NJ: Laurence Earlbaum Associates).

BILLINGS, C.E., 1995, Situation awareness measurement and analysis: A commentary. Proceedings of the International Conference on Experimental Analysis and Measurement of Situation Awareness (Daytona Beach, FL: Embry-Riddle Aeronautical University Press).

BLANDFORD, A. & WONG, W. 2005.

BLEAKLEY, A., ALLARD, J. & HOBBS, A. (2013) 'Achieving ensemble': communication in orthopaedic surgical teams and the development of situation awareness—an observational study using live videotaped examples. Advances in Health Sciences Education, 18, 33–56.

BOURBOUSSON, J., POIZAT, G., SAURY, J. & SEVE, C. (2011) Description of dynamic shared knowledge: an exploratory study during a competitive team sports interaction, Ergonomics, 54 (2), 120-138.

BRANTMAN 1992.

BRYANT et al 2004.

CARSTEN, O. & VENDERHAEGEN, F. (2015). Situation awareness: Valid or fallacious? Cognition, Technology & Work, VOL ISSUE PAGES

Dekker, S. (2015). The danger of losing situation awareness. Cognition, Technology & Work, 17:2, 59-161

DUL J, BRUDER R, BUCKLE P, CARAYON P, FALZON P, MARRAS. W. S, WILSON J.R. & VAN DER DOELEN B. 2012. A strategy for human factors/ergonomics: Developing the discipline and profession Ergonomics, 55 (4), 377-395.

ENDSLEY, M. R. 1988, Situation awareness global assessment technique (SAGAT). Proceedings of the National Aerospace and Electronics Conference (NAECON). (New York: IEEE), 789-795.ENDSLEY, M.R., 1993, A survey of situation awareness requirements in air-to-air combat fighters. *The International Journal of Aviation Psychology*, 3, pp. 157–168.

ENDSLEY M. R. 1995. Towards a theory of situation awareness in dynamic systems. Human Factors, 37, 32–64.

ENDSLEY M. R. 2015 JCEDM PAPER

ENDSLEY, M.R. and JONES, W.M., 2001, A model of inter- and intra-team situation awareness: Implications for design, training and measurement. In New Trends in Cooperative Activities: Understanding System Dynamics in Complex Environments, M. McNeese, E. Salas and M. Endsley (Eds.) (Santa Monica, CA: Human Factors and Ergonomics Society).

ENDSLEY, M.R. and ROBERTSON, M.M., 2000, Situation awareness in aircraft maintenance teams. International Journal of Industrial Ergonomics, 26, pp. 301–325.

FIORATOU, E., FLIN, R., GLAVIN, R. & PATEY, R. (2010) Beyond monitoring: distributed situation awareness in anaesthesia. British Journal Anaesthesia, 105 (1): 83-90.

FLACH, J. 1995. PROCEED WITH CAUTION. HUMAN FACTORS

FRACKER, M., 1991. Measures of situation awareness: review and future directions. Report No. AL-TR-1991–0128, Wright Patterson Air Force Base, Ohio: Armstrong Laboratories: Crew Systems Directorate.

GOBET, F. 1998. Expert memory: a comparison of four theories. Cognition, 66, 115-152.GOLIGHTLY, D., RYAN, B., DADASHI, N., PICKUP, L. & WILSON, J. R. (2013) Use of scenarios and function analyses to understand the impact of situation awareness on safe and effective work on rail tracks, Safety Science, 56, 52-62.

GOLIGHTLY, D., WILSON, J. R., LOWE, E. & SHARPLES, S. (2010) The role of situation awareness for understanding signalling and control in rail operations, Theoretical Issues in Ergonomics Science, 11:1-2, 84-98.

GRIFFIN, T.G.C., YOUNG, M.S. & STANTON, N.A. (2010) Investigating accident causation through information network modelling. Ergonomics, 53 (2), 198-210.

HAMILTON 1987

HANCOCK, P. A., MASALONIS, A. J. & PARASURAMAN, R. (2000). On the theory of fuzzy signal detection: theoretical and practical considerations. Theoretical Issues in Complexity Science, 1(3), 207-230.

HIGNETT, S., CARAYON, P., BUCKLE, P. & CATCHPOLE, K. (2013). State of science: human factors and ergonomics in healthcare. Ergonomics, 56:10, 1491-1503.

HAZELHURST, McCULLEN & GORMAN 2007

HUTCHINS, E., 1995a. How a cockpit remembers its speeds. Cognitive Science, 19, 265–288.

HUTCHINS, E., 1995b. Cognition in the wild. Cambridge, MA: MIT Press.

James, N., Patrick, J. (2004). The role of situation awareness in sport. In: S. Banbury and S. Tremblay, eds. A cognitive approach to situation awareness: theory, measures and application. London: Ashgate Publishers, 296-316.

KARWOWSKI, W. (2000). Cognitive ergonomics: requisite compatibility, fuzziness and nonlinear dynamics. Proceedings of the 14th Triennial Congress of International Ergonomics Association and the 35th Annual Meeting of the Human Factors Society. San Diego, CA, pp. 1-580-1-583.

KAUER, M., FRANZ, B., MAIER, A. & BRUDER, R. (2015). The influence of highly automated driving on the self-perception of drivers in the context of Conduct-by-Wire. Ergonomics, 58:2, 321-334.

LEE, J. D. (2001). Emerging challenges in cognitive ergonomics: managing swarms of self-organising agent-based automation. Theoretical Issues in Ergonomics Science, 2(3), 238-250.

LEE, W., KARWOWSKI, W., MARRAS, W. S. & RODRICK, D. (2003). A neuro-fuzzy model for estimating electromyographical activity of trunk muscles due to manual lifting. Ergonomics, 46(1), 285-309.

LEE, CASSANO-PINCHE & VICENTE 2005.

Ma, R. and Kaber, D.B. 2007. Situation awareness and driving performance in a simulated navigation task. *Ergonomics*, 50, 1351–1364.

MACQUET, A. & STANTON, N. A. (2014) Do the coach and athlete have the same 'picture' of the situation? Distributed Situation Awareness in an elite sport context. Applied Ergonomics. 45 (3), 724-733.

MORAY, N. 2004. Ou’ sont les neiges d0antan? In Human Performance, Situation Awareness and Automation; Current Research and Trends, D.A. Vincenzi, M. Mouloua and P.A. Hancock (Eds.), p. 4 (Mahwah, NJ: LEA).

NEVILLE, T. & SALMON, P. M. 2016. Never blame the umpire? A review of situation awareness models and methods for examining the performance of officials in sport. Ergonomics. Accepted for publication 8th September 2015

NIESSER, U. 1976. Cognition and Reality. Freeman Press, San Fancisco.

PATRICK, J. & MORGAN, P. L. 2010 Approaches to understanding, analysing and developing situation awareness, Theoretical Issues in Ergonomics Science, 11 (1-2), 41-57.

Patrick, J. and James, N., 2004a. A task-oriented perspective of situation awareness. In: S. Banbury and S. Tremblay, eds. A cognitive approach to situation awareness: theory, measures and application. London: Ashgate Publishers, 61–81.

PLANT, K. L. & STANTON, N. A. 2012. Why did the pilots shut down the wrong engine? Explaining errors in context using Schema Theory and the Perceptual Cycle Model. Safety Science, 50 (2), 300-315.

PLANT, K. L. & STANTON, N. A. 2013. The explanatory power of Schema Theory: Theoretical foundations and future applications in Ergonomics. Ergonomics 56 (1), 1-15.

PLANT, K. L. & STANTON, N. A. 2014. All for one and one for all: Representing teams as a collection of individuals and an individual collective using a network perceptual cycle approach, International Journal of Industrial Ergonomics, 44 (5), 777-792.

PLANT, K.L. & STANTON, N.A. 2015. The process of processing: exploring the validity of Neisser's perceptual cycle model with accounts from critical decision-making in the cockpit. Ergonomics, 58 (6), 909-923.

RASMUSSEN, J. ET AL 1994. CSE BOOK

RAFFERTY, L. A., STANTON, N. A. & WALKER, G. H. 2013. Great Expectations: A thematic analysis of situation awareness in fratricide. Safety Science, 56, 63-71.

REBER, A. S. (1995). The Penguin Dictionary of Psychology. London: Penguin.

REVELL, K. A. & STANTON, N. A. 2012. Models of models: filtering and bias rings in depiction of knowledge structures and their implications for design. Ergonomics 55 (9), 1073-1092.

ROUSSEAU, R., TREMBLAY, S. & BRETON, R. (2004). Defining and modeling situation awareness : A critical review. In S. Banbury & S. Tremblay (Eds) A cognitive approach to situation awareness: theory and application. Ashgate: Aldershot

SALAS, E., C. PRINCE, D. P. BAKER, AND L. SHRESTHA. 1995. Situation awareness in team performance: Implications for measurement and training. *Human Factors*, 37, 1123-136.

SALMON, P. M., LENNE, M. G., WALKER, G. H., STANTON, N. A. & FILTNESS, A. 2014. Exploring schema- driven differences in situation awareness across road users: an on-road study of driver, cyclist and motorcyclist situation awareness. Ergonomics, 57 (2), 191-209.

SALMON, P. M., READ, G. J. M., STANTON, N. A., & LENNE, M. G. 2013. The crash at Kerang: Investigating systemic and psychological factors leading to unintentional non-compliance at rail level crossings. Accident Analysis and Prevention, 50, 1278-1288.

SALMON, P. M. & STANTON, N. A. 2013. Situation Awareness and Safety: Contribution or Confusion? Safety Science 56, 1-5.

SALMON, P.M., STANTON, N.A., WALKER, G.H., JENKINS, D.P., 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., WALKER, G.H. & STANTON, N. A. 2016. Pilot error versus sociotechnical systems failure: a distributed situation awareness analysis of Air

France 447. Theoretical Issues in Ergonomics Science, 17 (1), 64-79.

SALMON, P.M., WALKER, G.H. & STANTON, N.A. 2015. Broken components versus broken systems: why it is systems not people that lose situation awareness. Cognition, Technology and Work, 17 (2), 179-183.

SARTER, N.B. & WOODS, D.D., 1991. Situation awareness – a critical but ill-defines phenomenon. International Journal of Aviation Psychology, 1, 45–57.

SCHULZ, C. M., ENDSLEY, M. R., KOCHS, E. F. GELB, A. W. & WAGNER, A. J. 2013. Situation Awareness in Anaesthesia: Concept and Research. Anaesthesiology, 118 (3), 729-742.

SEELEY, T.D., VISSCHER, P.K., SCHLEGEL, T., HOGAN, P.M., FRANKS, N.R., & MARSHALL, J.A. 2012. Stop signals provide cross inhibition in collective decision-making by honeybee swarms. Science, 335 (6064), 108-11.

SEPPÄNEN, H., MÄKELÄ, J., LUOKKALA, P. & VIRRANTAUS, K. 2013. Developing shared situational awareness for emergency management. Safety Science, 55, 1-9.

Sorensen, L. J., Stanton, N. A. & Banks, A. P. 2011. Back to SA school: contrasting three approaches to situation awareness in the cockpit. Theoretical Issues in Ergonomics Science, 12 (6), 451-471.

SHU, Y. and FURUTA, K., 2005, An inference method of team situation awareness based on mutual awareness. *Cognition Technology & Work*, 7, pp. 272–287.

Smith, K., and P. A. Hancock. 1995. Situation awareness is adaptive, externally directed consciousness. *Human Factors*, 37:1, 137-148.

SNEDDON, A., MEARNS, K. & FLIN, R. 2015. Stress, fatigue, situation awareness and safety in offshore drilling crews. Safety Science, 56, 80-88

SORENSEN, L. J. & STANTON, N. A. 2013. Y is best: How Distributed Situational Awareness is mediated by organisational structure and correlated with task success. Safety Science, 56, 72-79.

SORENSEN, L.J. & STANTON, N.A. 2015. Exploring compatible and incompatible transactions in teams. Cognition, Technology and Work, 17 (3), pp. 367-380

SORENSEN, L. J. & STANTON, N. A. 2016. Inter-rater reliability and content validity of network analysis as a method for measuring distributed situation awareness. Theoretical Issues in Ergonomics Science, 17 (1), 42-63.

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), 1-6.

STANTON, N. A. 2014. Representing Distributed Cognition in Complex Systems: How a submarine returns to periscope depth. Ergonomics, 57 (3), 403-418.

STANTON, N. A. 2016. Distributed situation awareness. Theoretical Issues in Ergonomics Science, 17 (1), 1-7.

STANTON, N. A., CHAMBERS, P. R. G. & PIGGOTT, J. 2001. Situational awareness and safety. Safety Science, 39, 189-204.

STANTON, N.A., SALMON, P.M. & WALKER, G.H. 2015. Let the reader decide: A paradigm shift for situation awareness in sociotechnical systems. Journal of Cognitive Engineering and Decision Making, 9 (1), 44-50.

STANTON, N. A., SALMON, P. M., WALKER, G. H., & JENKINS, D. P. 2009a. Genotype and phenotype schemata as models of situation awareness in dynamic command and control teams. International Journal of Industrial Ergonomics, 39 (3), 480-489.

STANTON, N. A., SALMON, P. M., WALKER, G. H., & JENKINS, D. P. 2009b. Genotype and phenotype schema 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), 29-40.

STANTON, N.A., STEWART, R., HARRIS, D., HOUGHTON, R.J., BABER, C., MCMASTER, R., SALMON, P., HOYLE. G., WALKER, G., 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. & WALKER, G. H. 2011. Exploring the psychological factors involved in the Ladbroke Grove rail accident. Accident Analysis and Prevention, 43(3), 1117 - 1127.

STEWART, R., STANTON, N. A., HARRIS, D., BABER, C., SALMON, P. M., MOCK, M., TATLOCK, K., WELLS, L. & KAY, A. 2008. Distributed situation awareness in an airborne warning and control system: application of novel ergonomics methodology. Cognition Technology and Work, 10 (3), 221 – 229.

TAYLOR, R.M., 1990. Situational Awareness Rating Technique (SART): The development of a tool for aircrew systems design. In: Situational Awareness in Aerospace Operations (AGARDCP- 478) pp. 3/1–3/17 (Neuilly Sur Seine, France: NATO-AGARD).

RAFFERTY, L. A., STANTON, N. A. & WALKER, G. H. 2013. Great Expectations: A thematic analysis of situation awareness in fratricide. Safety Science 56, 63-71.

VICENTE, K. J. 1999. Cognitive Work Analysis: Toward Safe, Productive, and Healthy Computer- Based Work. Lawrence Erlbaum Associates, Mahwah, NJ.

WALKER, G. H., STANTON, N. A. & CHOWDHURY, I. 2013. Situational awareness and self explaining roads. Safety Science, 56, 18-28

WALKER, G. H., STANTON, N. A. & YOUNG, M. S. 2008. Feedback and driver situation awareness (SA): A comparison of SA measures and contexts. Transportation Research Part F: Traffic Psychology and Behaviour, 11 (4), 282-299.

WALKER, G. H., STANTON, N. A., KAZI, T. A., SALMON, P. M., & JENKINS, D. P. 2009. Does advanced driver training improve situation awareness? Applied Ergonomics, 40 (4), 678-87.

WALKER, G. H., STANTON, N. A., SALMON, P. M., JENKINS, D. P. & RAFFERTY, L. 2010. Translating concepts of complexity to the field of ergonomics. Ergonomics, 53(10), 1175 - 1186.

WALKER, G. H. 2016. Fortune favours the bold. Theoretical Issues in Ergonomics Science, On-Line Pre Publication Version.

WELLENS, A.R., 1993, Group situation awareness and distributed decision making: From military to civilian applications. In Individual and Group Decision Making: Current Issues, N.J. Castellan (Ed.), pp. 267–287 (Mahwah, NJ: Erlbaum Associates).

WICKENS, C. D. 2008. PAPER ON ENDSLEYS SA STUFF

WILSON, J. R. 2012. Fundamentals of systems ergonomics. Work, 41, 3861-3868.

WOODS, D. D. & DEKKER, S. (2000). Anticipating the effects of technological change: a new era of dynamics for human factors. Theoretical Issues in Ergonomics Science, 1(3), 272-282.

VAN WINSEN, R. & DEKKER, S. W. A. 2015. SA Anno 1995: A commitment to the 17th century. Journal of Cognitive Engineering and Decision Making, 9(1), 51-54.

WOODS, D.D. & DEKKER, S. 2000. Anticipating the effects of technological change: a new era of dynamics for human factors. Theoretical Issues in Ergonomics Science, 1 (3), 272–282.

YOUNG ET AL 2015 State of Science: Mental Workload. Ergonomics, VOL, PAGES.