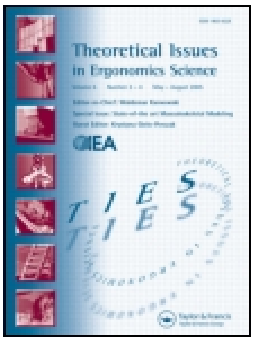

Theoretical Issues in Ergonomics Science

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Distributed situation awareness

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EDITORIAL

Distributed situation awareness

1. Introduction to DSA

The argument put forward in this special issue of TIES (Theorectical Issues in Ergonomics Science) favours a socio-technical systems theoretic approach to situation awareness (SA). This journal is concerned with all matters pertaining to Theoretical Issues in Ergonomics Science (Stanton 2002), so it is fitting to consider the developments in distributed situation awareness (DSA). It is 10 years since the DSA theory and methodology were originally proposed (Stanton et al. 2006). The DSA approach takes both human and technical agents as well as the way in which they interact into consideration. Socio-technical systems theory also offers the key to mediation between the different positions taken on SA. The systems theoretic approach is potentially useful in addressing the interaction between sub-components in systems. Systems theory proposes a hierarchical order of system components, i.e. all structures and functions are ordered by their relation to other structures and functions and any particular object or event comprises lesser objects and events. Thus, when examining a system, the level and boundaries need to be declared. The resolution that is proposed is that viewing SA 'in-mind', 'in-world' or 'in-interaction' is a declaration of the boundaries that are applied to the analysis. This is not to say that one position is necessarily right or wrong, rather those boundaries are declared openly in the analysis. The DSA perspective is not without its critics however, which have been addressed in two recent commentaries (Stanton, Salmon, and Walker 2015; Salmon, Walker, and Stanton 2015).

2. How DSA works

In his seminal papers on distributed cognition, which have served as inspiration for DSA, Hutchins (1995a, 1995b) described how socio-technical systems work in practice. He proposed that socio-technical systems have cognitive properties and these are not reducible to the properties of individuals. By way of an example, Hutchins chose to examine an aircraft cockpit, focusing on the division of work between the 'agents' in the cockpit on approach for landing. The term 'agents' has been chosen to represent both the aircrew and the cognitive artefacts. The landing tasks present an interesting case study because the speed of the aircraft and the flaps and slats in the wing require precise adjustments at set points on the descent. The changes in speed and the flaps/slats need to be undertaken in concert, in order to avoid undue stress being placed on the wings. These settings cannot simply be memorised by the aircrew, as they are highly dependent on the weight of the aircraft. In the example presented by Hutchins (1995a), 4 different speeds are required by different points on the approach and descent: starting at 245 knots, the airspeed has reduced to 227 knots, then 177, 152 and finally to 128 knots. Each reduction in speed is accompanied by a change in the wing's configuration, either by moving the flaps and/or slats. To assist in the task, the pilot relies heavily upon external representation of the speed settings. Devices called 'speed bugs' (black pointers that can be moved around the airspeed indicator dial – each with its own flap and slat setting name) are set by the pilot before the approach and descent. The pilot gets the speed settings from a speed card in the aircraft speed card booklet after working out the weight of the aircraft. Then the speed bugs can be set ready for the approach, one bug assigned to each of the four speed settings. Clearly, the pilots are no longer required to remember the speed settings of the aircraft (Stanton et al. 2010; Sorensen, Stanton, and Banks 2011).

Depending on the stage of flight, different 'agents' in a socio-technical system will have different awareness of a system. These agents are likely to comprise the artefacts in the cockpit (such as the fuel quantity indicator, speed cards, airspeed indicator, altimeter), the pilot flying and the pilot not flying, the air traffic controller, the radar and flight strips in air traffic control. Taking the entire socio-technical system in the cockpit as the unit of analysis during the descent tasks, DSA focuses at the transactions between the pilots and the artefacts to understand how the aircraft undertakes the descent tasks and what each of the 'agents' is aware of at any given point in time. This approach would show that the pilots hold information about changes in flaps and slats settings with a given point on approach and descent, whereas the speed bugs hold information about the required speed associated with that flaps and slats setting (Sorensen, Stanton, and Banks 2011). It is only when the two sub-systems interact (the social sub-system in terms of the pilots and the technical sub-system in terms of the air speed indicator, speed bugs flaps and slats controls), that one can begin to understand how DSA is maintained in the cockpit. Hutchins (1995a) points out that the cognitive processes are distributed amongst the agents in the system, some are human and others are not. The difference between this view and that of Endsley (1995) is that the DSA view holds that the socio-technical system is the unit of analysis, whereas the three-level SA view holds that the individual mind is the unit of analysis. DSA is concerned with the transactions between agents and the physical structure of the environment in socio-technical systems (Stanton et al. 2010).

To further understand how this system might work, imagine a network where nodes are activated and deactivated as time passes in response to changes in the task, environment and interactions (both social and technological). In regard to the system as a whole, it does not matter if humans or technology own this information, just that the right information is activated and passed to the right agent at the right time. This idea is founded on the theory of 'transactional memory', which involves the reliance that people have on other people (Wegner 1986) and machines (Sparrow, Liu, and Wegner 2011) to remember for them. It does not matter if the individual human agents do not know everything (indeed, it would be impossible for them to), provided that the system has the information, which enables the system to perform effectively (Hutchins 1995b). We know that agents are able to compensate for each other, enabling the system to maintain safe operation. This dynamism is impossible to model using reductionist, linear approaches. The systems thinking paradigm provides the necessary theoretical foundations and tools to explore the nonlinearity experienced in complex socio-technical systems (Walker et al. 2010).

3. DSA theory

These fundamental ideas of DSA in a system lead to a set of tenets that form the basis of the theory (Stanton et al. 2006). These propositions, which have been updated for this special issue, are as follows:

1. SA is held by human and non-human agents. Technological artefacts (as well as human operators) have some level of SA (at least in the sense that they are holders of contextually relevant information). This is particularly true as technologies are able to sense their environment and become more animate.
2. Different agents have different views on the same scene. This draws on schema theory, suggesting the role of past experience, memory, training and perspective. Animate technologies may be able to learn about their environment.
3. Whether or not, one agent's SA overlaps with that of another depends on their respective goals. Different agents could actually be representing different aspects of SA.
4. Transactions (in the form of communications and interactions) between agents may be verbal and non-verbal behaviour, customs and practice (but this may pose problems for the non-native system users). Technologies transact through sounds, signs, symbols and other aspects relating to their state.
5. SA holds loosely coupled systems together. It is argued that without this coupling the systems performance may collapse. Dynamical changes in system coupling may lead to associated changes in DSA.
6. One agent may compensate for degradation in SA in another agent. This represents an aspect of the emergent behaviour associated with complex systems.

In the original paper specifying the DSA theory and approach, Stanton et al. (2006) indicate how the system can be viewed as a whole, by consideration of the information held by the artefacts and people as well as the way in which they interact and transact. The dynamic nature of SA phenomena means they change moment by moment, in light of changes in the task, environment and interactions (both social and technological). These changes need to be tracked in real time if the phenomena are to be understood (Patrick et al. 2006). DSA is considered to be activated knowledge for a specific task within a system at a specific time by specific agents, that is, the human and non-human actors in a system. Although this perspective can be challenging when viewed through a cognitive psychology lens, from a systems perspective it is not (Hollnagel 1993; Wilson 2012). Thus, one could imagine a network of information elements, linked by salience, being activated by a task and belonging to an agent – the 'hive mind' of the system (Seeley et al. 2012). For a more complete explanation of DSA theory and measurement, the interested reader is referred to the books by Stanton, Baber and Harris (2008) and Salmon, Stanton, Walker, and Jenkins (2009).

4. Applications of DSA

The theory has led DSA research into many new domains, including road design (Walker, Stanton, and Chowdhury 2013), evaluation of road systems and road user behaviour (Salmon et al. 2014; Salmon, Stanton, and Young 2012), advanced driver training (Walker et al. 2009), human supervisory control (Stanton et al. 2009), aviation accident investigation (Griffin, Young, and Stanton 2010) and submarine control rooms (Stanton 2014a). The DSA approach has been used in many other studies, including the five presented here. Two of the papers focus on laboratory-based experimental studies, one is an analysis of an accident and two are based on observations of dynamic domains. This journal is also concerned with the reliability and validity of Ergonomics theory and methods (Stanton 2014b), which are also addressed in the special issue papers. The five domains covered in the special issue are: monitoring of vehicles, command and control, aviation, football, and medicine. All five domains share the need to consider DSA from a dynamical systems perspective.

In the first paper, Kitchin and Baber (a comparison of shared and distributed situation awareness in teams through the use of agent-based modelling) conducted an experimental study of small three person teams undertaking a rogue vehicle detection task at simulated toll-booth. The teams are required to monitor vehicles on screens and report on any illegal vehicles. The experiment was set up so that teams either had the information in the same or different views of the situation, to test the shared versus distributed SA theories. Kitchin and Baber used concept maps as a useful method of representing awareness held within a system. The results of the experiment suggest that the higher performing teams' concept map data was akin to DSA as shown by more information spread around the system. Those teams that shared the same information appeared to perform worse than those that had different views on the situation. This has important implications for the design of Common Operating Picture displays, suggesting that they need to be role specific. Kitchin and Baber conclude that the DSA approach promotes higher performance in teams than the shared SA approach.

In the second paper, Sorensen and Stanton (Inter-rater reliability and content validity of network analysis as a method for measuring Distributed Situation Awareness) undertook a study to analyse the reliability and validity of methods to produce the concept maps (in Leximancer – a textual analysis software tool) that are used to represent DSA. The study was based around an experimental command and control tasks, where five participants are required to capture 'enemy' positions whilst simultaneously avoiding 'neutrals' and uncovering 'unknowns'. Two data collections techniques were compared: text message communications between participants and Critical Decision Questionnaire responses at the end of each trial. The study showed a very high level of reliability between the analysts and Leximancer in coding of the transcripts from both the text message communications between participants and Critical Decision Questionnaire responses, which is encouraging. The study of content validity showed that the text message communications between participants had more relevance than the Critical Decision Questionnaire responses. Sorensen and Stanton surmise that this indicates that use of communication logs for construction of the networks is preferable for the representation of DSA.

In the third paper, Salmon, Walker and Stanton (Pilot error versus sociotechnical systems failure? A DSA analysis of Air France 447) also consider a disaster from a systems perspective, in this case, an infamous aviation accident. They argue that although the official report put much of the blame on the pilots of the aircraft, this is at odds with contemporary thinking in Ergonomics Science. From a DSA perspective, the unit of analysis should be the whole socio-technical system rather than individuals. Salmon et al. draw on the DSA theory to put forward the idea of the 'hive mind' of the system and propose that the investigation should have focused on the 'transactions' between system agents to get a more accurate understanding of events. Moreover, it is the 'system' that loses awareness rather than individuals. Salmon et al. identify three main phases in the incident: entrance into the intertropical convergence zone (ITCZ) until the autopilot disconnects, the aircrew's response to the disconnection and the return of the captain to the cockpit. Their analyses show significant decrements to DSA in all three phases. In the analysis, Salmon et al. identify four classes of transaction failure that directly contributed to the accident: absent transaction, inappropriate transactions, incomplete transactions and misunderstood transactions. All incidents are likely to have one or more of these classes of system failures present.

In the fourth paper, Neville, Salmon, Read and Kalloniatis (Play on or call a foul: Testing and extending distributed situation awareness theory through sports officiating) consider the application of the original six tenets of DSA (see Section 3 on DSA theory) to officials in sport (such as referees, umpires, judges and stewards) specifically Australian Football League (AFL). Neville et al. use the EAST (Event Analysis of Systemic Teamwork: Stanton et al. 2008) methodology to build up social, information and task networks, so that the tenets could be evaluated with respect to the AFL. They conclude that the original tenets are still relevant today and apply just as well to the AFL as they do in other domains. Neville et al. argue that tenet four on communications should be updated to included transactions, which has occurred over the past decade as much has been written and researched on transactions between agents. They also argue that tenet five on coupling could be modified to consider system dynamics, to describe how the transition between loose and tight coupling occurs. Arguably, DSA acts as a facilitator between these transitions. In summary then, the tenets of DSA have stood the test of time and, together with the associated EAST methodology, provide a useful way of investigating and improving performance of systems.

In the final paper, Fioratou, Chatzimichailidou, Grant, Glavin, Flin and Trotter (Beyond monitors: Distributed Situation Awareness in anaesthesia management) take a socio-technical and distributed cognition perspective to major obstetric hemorrhage management, using the critical decision method to collect data and DSA to analyse the results. The extended system associated with major obstetric hemorrhage management includes: the patient, anaesthetic team, surgical team, nursing team, other professionals (e.g., midwife and haemetologist), technical equipment, and the patients partner, friend or family member. The analysis of the data collected via the critical decision method revealed that the consultant anaesthetist uses information from all manner of sources (as reflected in the paper title) dynamically in what is a fast changing situation. There is evidence for the reciprocity of transactions between all of the agents in the system, showing that DSA is a useful framework for healthcare professionals. Fioratou et al. argue that DSA is useful for both understanding and improving the complex socio-technical system of the operating theatre as it can have a beneficial impact on patient safety.

Other researchers are beginning to catch on and find the DSA concept, theory and methodology useful in their work, including, but not restricted to Bourbousson et al. 2011; Fioratou et al. 2010; Golightly et al. 2013; Golightly et al. 2010; Macquet and Stanton 2014; Patrick and Morgan 2010; Haavik 2011; Schulz et al. 2013. The groundswell of evidence suggests that DSA has much to offer to our understanding of some of the complexities of socio-technical systems, and this is just the beginning.

5. Conclusions

Over the past decade, much research and application of DSA has been undertaken, beyond the group of people originally involved in those original studies. It is fair to say that the theory and methods have matured over those 10 years and it is pleasing to see that DSA has been applied in all manner of domains. So far, the application of DSA has led to encouraging results. The take-home messages from the five papers presented in this special issue are as follows:

- DSA offers explanations of the behaviour of complex socio-technical systems in a wide range of domains;
- DSA promotes higher performance in teams than shared SA;

- the empirical data on the reliability and validity of DSA are promising;
- the DSA perspective helps to explain accident causality of accidents in complex socio-technical systems; and
- the original tenets underpinning the DSA theory have stood the test of time and even modifications are within the original theory.

In summary then, it is concluded that the DSA perspective has much to offer the researcher and practitioner of Ergonomics Science. It is hoped that readers of this special issue will be inspired by the papers and take DSA into their own domains, to further develop the theory and methods. They are encouraged to report on any developments, especially on the reliability and validity, within this journal.

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