Let the reader decide: a paradigm shift for situational awareness in socio-technical systems

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Abstract

In science and engineering there is a natural rise and fall of paradigms as progress is made. In this way a new paradigm becomes more established until it gives way to new developments. We think it is legitimate to raise concerns over the status quo and propose new paradigms This is how science moves forward, but we do recognise that paradigm owners tend to resist change. We contend that DSA presents a new paradigm for analysing and explaining SA in systems, and there is a groundswell of studies that are tipping the balance of evidence in that direction.

Keywords: Situation Awareness, Distributed Cognition, Cognitive Modelling

Systems thinking

Credit where it is due, Endsley's original 1995 paper in Human Factors has done more to raise the general consciousness to the idea of situation awareness than any single article before or since. For that we are grateful. The world of research has not remained static however, and its focus in Human Factors has shifted from the individual person to whole systems (Hutchins, 1995; Rasmussen, 1997; Leveson, 2004; Walker et al, 2009a; Wilson, 2012). We think it is legitimate to raise concerns over the status quo and propose new paradigms (Salmon et al, 2008a, 2009;; Sorensen et al, 2011; Stanton et al, 2009, 2010). This is how science moves forward, but we do recognise that paradigm owners tend to resist change. We offer this commentary in the spirit of detached, calm, and reasoned academic debate. Distributed Situation Awareness (DSA) is presented as an alternative way of thinking about Situation Awareness (SA) in systems. As Hutchins (1995) advocated, the unit of analysis is not the individual person, or even teams of people (as presented with the three-level model), but the entire system under investigation. This notion has gained considerable credence within Human Factors, Hollnagel (1993) even suggesting that, due to the complexity of modern day socio-technical systems, the study of information processing in the minds of individuals has lost relevance.

It is easy for the research community to fall into the fallacy of the linear flow of the Endsley model based on the original paper (1995). Italics have been added for emphasis:

"*The first step* in achieving SA is to perceive the status, attributes, and dynamics of relevant elements in the environment" (page 36)

"Comprehension of the situation *is based on* the synthesis of disjointed level one elements" (page 36)

"*Based on* knowledge of level one elements, particularly when put together to form patterns with the other elements (gestalt) the decision maker forms a holistic picture of the environment, comprehending the significance of objects and events" (page 37)

"... the *third and highest level of SA*. This is achieved through knowledge of the status and dynamics of the elements and comprehension of the situation (both level 1 and level 2 SA)." (page 37).

A later publication exacerbates this confusion (Endsley and Jones, 2012):

"*The first step* in achieving SA is to perceive the status, attributes, and dynamics of relevant elements in the environment." (page 14).

"*The second step* in achieving good SA is understanding what the data and cues perceived mean in relation to relevant goals and objectives. Comprehension (level 2 SA) *is based on* a synthesis of disjointed level 1 elements [..]" (page 16).

And finally:

"*A person can only achieve level 3 SA by having a good understanding of the situation (Level 2 SA) and the functioning and dynamics of the system they are working with*" (page 18).

We agree with Endsley that there are subtleties, what we disagree about is the ability of the three-level model to cope with them (Salmon et al, 2009a, b; Sorensen et al, 2011). On the one hand Endsley (this issue) puts forward seven fallacies which it is felt other models fall into and promulgate through the literature, causing confusion. On the other hand is the much simpler idea that due to the complexity of the socio-technical systems which form the subject of much contemporary analysis, the study of information processing in the mind of individuals has lost relevance (Hollnagel, 1993). Endsley and colleagues have made unquestionably good progress on numerous thorny psychological issues around their model, but we contend there is a much more elegant solution; instead of looking at the information processing of a person (or persons) embedded in a situation, look instead at the interactions or transactions that take place between actors. From nodes to links: this is the main essence of DSA and indeed other human factors systems thinking approaches (e.g. Rasmussen, 1997). This approach overcomes the much more fundamental fallacy that we cannot ever know completely what is going on in peoples' minds (Dekker et al, 2010; Dekker, 2013). We therefore invite the reader with an open mind on our journey of discovery and let them decide for themselves.

Going out into the world – Observational Studies of Command and Control

Our interests in situation awareness began with studies of teams in military (Stanton et al, 2006; Stewart et al, 2008; Stanton et al, 2009a) and civilian (Salmon et al, 2008a; Stanton et al, 2009b; Walker et al, 2010) command and control domains. We were faced with the task of collecting exhaustive data on how multi-person teams distributed across multiple locations performed in training and real operational settings, but were unable to interfere with their tasks, and certainly not allowed to interrupt their work. Thus our methods had to be non-intrusive and naturalistic. Despite initially wanting to apply SAGAT, these real-life demands meant that we could not use the approach and had to rely on other data collection methods, such as recording of conversations and communications (Rafferty et al, 2012) and post-hoc interviews using the Critical Decision Method (Klein et al, 1989). In the air traffic domain, for example, we recorded all of the communications from the controller's desks and video recorded their activity (Walker et al, 2010). In the naval domain we had access to all of the voice communications in the command team as they performed their training activities (Stanton et al, 2006). In the energy distribution domain we had access to procedures, voice communications, and critical decision method interview transcripts (Salmon et al, 2008a). When it came to analysing these data, it was clear we had direct access to exactly what was going on in the command and control teams and were able to represent the system's awareness in its entirety using propositional networks. These networks can be used to understand the dynamics of awareness as it changes and propagates through a system. Through this the distributed nature of awareness became very apparent to us (Stanton et al, 2006; Stanton et al, 2008; Salmon et al, 2008b; 2009a; Walker et al, 2010; Walker et al, 2006). It is clear that in these types of environments each 'agent in the system' has quite different goals and tasks and consequently has a very different understanding of the situations they were working in, even when presented with the some or all of the same data. This view offers compelling and useful insights into the distributed nature of awareness in complex socio-technical systems.

Going back into the lab – testing SAGAT

We have tried hard to be good three-level theorists in our experimental studies; we were concerned with the way in which media could be designed to keep distributed teams involved in a collaborative task (Walker et al. 2009b). Different media were investigated to support the collaboration. There were four conditions: voice only (a telephone link between participants); voice and video (a live video link between participants); voice and data (an electronic shared workspace); voice, video and data (all three media). The participants had to undertake a simulated mission-planning task. At various stages in this task, the participants were stopped and they were asked questions about the tasks consistent with levels one, two and three of Endsley's model via the SAGAT method (the freeze, blank and probe approach). The measure of SA had been expected to indicate better media for supporting the distributed team. In the event, SAGAT results showed best performance on the worst, voice-only condition. As the media became richer, the SAGAT scores became poorer. Whilst it seems obvious now, it was against the hypothesis that SA would be better in the media-rich condition (i.e., voice, video and data). The explanation lies in the greater the support from the environment, the less the person has to remember as the artefacts in the system hold the information (similar to the manner in which mobile phones hold our contact numbers). In the same way that pilots use the speed bugs to remember for them (Hutchins, 1995), the participants were using the video and shared electronic workspace to remember. Similar findings are being reported in the wider literature (Sparrow, 2011). The awareness of the system was distributed across the agents and media and therefore the levels of SA held 'in-the-heads' of participants, as scored by the SAGAT approach, were found to be poor. Only when deprived of the support were the human agents forced to remember the planning details. If this information was taken at face value, it might have led to recommending the poorest medium for the design of the system (i.e. voice only). In the end, it was realised that it was necessary to consider the system as a whole, the socio-technical view of DSA led to a different, and considerably richer, conclusion for system design. This theory has led us into many new domains, including road design (Walker et al, 2012), evaluation of road systems and road user behaviour (Salmon et al, 2012, In Press) and advanced driver training (Walker et al, 2009c).

DSA as the alternative paradigm

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 and the way in which they interact. 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. By agent, it is intended to mean either a human or non-human actor in a system. Whilst this can be challenging when viewed through a cognitive psychology lens, from a systems perspective it is not (e.g. Hutchins, 1995; Rasmussen, 1997; Leveson, 2004; Walker et al, 2009a; 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, if you will (Seeley et al, 2012). To understand how this 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). Viewing 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 discovered the reliance that people have other people (Wegner, 1986) and machines (Sparrow et al, 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, 1995). We know that agents are able to compensate for each other, enabling the system to maintain safe operation (i.e., there is no one best way – as described by the advocates of Cognitive Work Analysis, see Vicente, 1999). This dynamism is impossible to model using reductionist, linear, approaches. The systems thinking paradigm provides the necessary theoretical foundations and tools to explore the non-linearity experienced in complex socio-technical systems (Walker et al, 2010). For a more complete explanation of DSA theory and measurement, the interested reader is referred to the book by Salmon et al (2009).

One of the core misconceptions expressed by Endsley (this issue) is that the DSA approach has no accompanying methodology to support the design of systems nor to undertake analyses of DSA in the wild. This is incorrect. The EAST methodology (see Stanton et al, 2013), which incorporates the propositional network approach to describe DSA, has been applied pro-actively to model DSA across different system design concepts (Baber et al, 2013) and used to assess DSA in all manner of complex naturalistic settings (e.g. Salmon et al, 2008; Stanton, In Press; Walker et al, 2013). In addition, the authors have used EAST to generate DSA requirements specifications in systems design. For example, this approach was used by the authors to examine DSA during a large scale UK Army field trial of a new £2.4bn mission planning and battlespace management system (Stanton et al, 2009). The DSA approach was the only methodology that could be usefully applied to assess situation awareness in this complex naturalistic setting. Based on live observations the DSA analysis identified system design issues adversely impacting on DSA (Salmon et al, 2009). The outputs were used to generate concrete system redesign recommendations (Stanton et al, 2009) which have been subsequently implemented. Consequential improvements in system performance were observed.

The relationship between SA and task performance has remained resolutely difficult to prove, some research both proving and falsifying the link, even within the same study (Endsley, 1995). This begs the question of why bother with SA if it is not telling us anything about how teams actually perform on tasks? The systems view of SA is not as equivocal. We have conducted experimental research into the conversations teams have when performing tasks and found a very strong positive relationship between DSA and the team's performance on the task (Sorensen and Stanton, 2013). We have also shown the same effect in high fidelity, pre-deployment, training environments (Rafferty et al., 2013). DSA, therefore, does tell us how teams actually perform, making SA as a concept more, rather than less, useful. This is a key insight that has been supported by the research of others (Bleakey et al, 2011; Golightly et al, 2013; Patrick and Morgan, 2010).

Revolutionary newcomer

In science and engineering there is a natural rise and fall of paradigms as progress is made. In this way a new paradigm becomes more established until it gives way to new developments. We contend that DSA presents a new paradigm for analysing and explaining SA in systems, and there is a groundswell of studies that are tipping the balance of evidence in that direction (Bourbousson et al, 2011; Fioratou et al, 2010; Golightly et al, 2010; Golightly et al, 2013; Macquet and Stanton, 2014; Patrick and Morgan, 2010 and others). We do not expect the debate to end here, but we do encourage the reader to approach all of the ideas with an open mind, try out the approaches and decide for themselves (e.g., Haavik, 2011; Schulz et al, 2013).

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