Distributed Situation Awareness

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Abstract. This paper presents contemporary thinking on Distributed Situation Awareness (DSA). This has developed over the past decade from a concept into a testable theory with associated methodology. Early forays into understanding the nature of DSA are presented together with examples of case applications. The tenets of the original research paper have remained robust over the past decade and are presented in this paper. DSA is based on the original ideas from Distributed Cognition, which have been extended to show how systems might have awareness. The unit of analysis for DSA has been as declared as the whole Socio-Technical System.

Keywords. Situation Awareness, Socio-Technical Systems, Teams, Theory

1. Introduction to DSA

The argument put forward in this paper favours a socio-technical systems theoretic approach to Situation Awareness (SA). This 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 subcomponents 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 that those boundaries are declared openly in the analysis.

2. How DSA works

In his seminal papers on distributed cognition, which have served as inspiration for Distributed Situation Awareness (DSA), Hutchins (1995a,b) described how socio-technical systems work in practice. He proposed that socio-technical systems have cognitive properties and that 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), four different speeds are required by different points on the approach and descent: starting at 245 knots (kn) the airspeed has be reduced to 227 kn, then 177 kn, then 152 kn and finally to 128 kn. 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.

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 on 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. 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 and colleagues 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.

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, & Wegner, 2011) to remember for them. It does not matter if the individual human agents do not know everything (indeed, this would be impossible), provided that the system has the information that 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 SA distributed in a system lead to a set of tenets that form the basis of the theory (Stanton et al., 2006). These propositions are as follows:

1. SA is held by human and non-human agents. Technological artefacts (as well as human operators) have some level of situation awareness (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 that 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 represent different aspects of SA.
4. Communication between agents may be non-verbal behaviour, customs and practice (but this may pose problems for non-native system users). Technologies may give off non-verbal cues 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.
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 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, James, Ahmed, & Halliday, 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 nonhuman 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, if you will (Seeley et al., 2012). For a more complete explanation of DSA theory and measurement, the interested reader is referred to the book by Salmon, Stanton, Walker, and Jenkins (2009).

4. DSA Applications

The theory has led DSA research into many new domains, including road design (Walker, Stanton, & Chowdhury, 2013), evaluation of road systems and road user behaviour (Salmon, Lenne, Walker, Stanton, & Filtness, 2014; Salmon, Stanton, & Young, 2012), advanced driver training (Walker, Stanton, Kazi, Salmon, & Jenkins, 2009), aviation accident investigation (Griffin, Young & Stanton, 2010), and submarine control rooms (Stanton, 2014). The DSA approach has been used in many other studies, including the four presented here.

The very first application of DSA was undertaken in at HMS Dryad Type 23 frigate operations control room simulator, by recording all radio exchanges. The anti-air warfare officer (AAWO) was observed during the air threat, and the principal warfare officer (PWO) was observed during the subsurface and surface threats. All forms of communication were recorded, including verbal exchanges not communicated via radio, hand gestures, and written communication (on paper). Within these scenarios there are four main agents: the officer of the watch (OOW), the PWO, the AAWO, and the captain. The OOW is an officer on the ship's bridge who maintains the visual lookout and controls the ship. The OOW can overrule the manoeuvring orders from the operations room if he/she considers them to be inappropriate. The PWO is responsible for the tactical handling of the ship and the integrated use of its weapons systems and sensors. The PWO takes a tactical command role in multi-threat missions. The AAWO is responsible for the plan of defence in response to an air attack. The captain oversees the operations room. In addition to personnel, the ship has a computer-based command system, which can communicate and control weapons and sensor systems, allowing information to be passed independently of the command system itself. An information network was constructed for the surface, subsurface and air threat tasks. The total situation for the system under analysis was described by 64 information elements. The information network makes no reference to any particular job roles, and technology is only referred to in a general sense (e.g. weapons, satellite, radar, and sonar). While this is a general system-level representation, activation of any of the knowledge objects was been identified with particular tasks from the task. This activation of the information network illustrates the ideas governing DSA of the system in a very literal sense.

In another application, a field trial of a new £2.4 billion mission-planning and battlespace management system was undertaken (Stanton, Walker, et al., 2009). For our purposes, the DSA approach was considered by the research team to be the most appropriate methodology that could be applied to assess SA in this complex naturalistic setting because of the dynamic nature of the activities. It would be impossible to 'script' the system activities and metrics ahead of time, as the planning and operations teams had to adapt to the changing nature of the environment. Based on live observations, the DSA analysis identified design issues adversely affecting system performance (Salmon, Stanton, Walker, Jenkins, Ladva, et al., 2009). The outputs were used to generate explicit system redesign recommendations (Stanton, Walker, et al., 2009) that have been subsequently implemented. Consequential improvements in system performance were observed.

In the third application, DSA has also been studied in the energy distribution domain (see Salmon et al. 2008) to demonstrate the concepts of compatible and transactive aspects of SA. This study demonstrated how the activities and transactions that occurred within the energy distribution system can be mapped onto the perceptual cycle model. The first transaction to take place is the issue of instructions by the operator. This serves to update each schema of the system and of the work required, which in turn drives the activities that the system then undertakes. The outcome of these activities is then checked by the others in the field and the operator at the control centre (via circuit displays), which in turn modifies both the systems and the field and operator schema of the current status of the system. The study demonstrated how the cyclical perception-action notion can be applied to the entire system as well as the teams and individuals working within it.

Finally, a laboratory study has demonstrated way in which media could be designed to keep distributed teams involved in a collaborative task (Walker, Stanton, Salmon, & Jenkins, 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), and voice, video, and data (all three media). The findings showed better system performance in the media-rich condition (i.e., voice, video, and data). The explanation lies in the fact that 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 contact numbers). In the same way that pilots use the speed bugs to remember for them (Hutchins, 1995a), the participants were using the video and shared electronic workspace to remember. Comparable findings are being reported in the wider literature (Sparrow, Liu, & Wegner, 2011). The awareness of the system was distributed across the agents and media. The sociotechnical view of DSA led to a different, and considerably richer, conclusion for system design.

The relationship between SA and task performance has remained resolutely difficult to prove, with some research both proving and falsifying the link, even within the same study (Endsley, 1995), which begs the question, why bother with SA if it is not revealing anything about how teams actually perform on tasks? The systems view of SA is not as equivocal. Research into the conversations teams have when performing tasks has found a very strong positive relationship between DSA and the teams' performance on the task (Sorensen & Stanton, 2013). The research has also shown the same effect in high-fidelity, predeployment 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.

5. Conclusions

In Ergonomics and Human Factors, 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. It is contended that DSA presents a new paradigm for analyzing and explaining SA in systems, and there is a groundswell of studies that are tipping the balance of evidence in that direction. The debate is not expected to end here, but readers are encouraged to approach all of the ideas with an open mind, try out the approaches, and decide for themselves.

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