Applied Ergonomics 61 (2017) 178–196

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

The Situation Awareness Weighted Network (SAWN) model and method: Theory and application

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A R T I C L E I N F O

Article history:
Received 13 July 2016
Received in revised form
22 December 2016
Accepted 2 February 2017
Available online 14 February 2017

Keywords:
Situation awareness
Empirical model
Case studies
Network analysis

A B S T R A C T

We introduce a novel model and associated data collection method to examine how a distributed organisation of military staff who feed a Common Operating Picture (COP) generates Situation Awareness (SA), a critical component in organisational performance. The proposed empirically derived Situation Awareness Weighted Network (SAWN) model draws on two scientific models of SA, by Endsley involving perception, comprehension and projection, and by Stanton et al. positing that SA exists across a social and semantic network of people and information objects in activities connected across a set of tasks. The output of SAWN is a representation as a *weighted semi-bipartite network* of the interaction between people ('human nodes') and information artefacts such as documents and system displays ('product nodes'); link weights represent the Endsley levels of SA that individuals acquire from or provide to information objects and other individuals. The SAWN method is illustrated with aggregated empirical data from a case study of Australian military staff undertaking their work during two very different scenarios, during steady-state operations and in a crisis threat context. A key outcome of analysis of the weighted networks is that we are able to quantify *flow of SA* through an organisation as staff seek to "value-add" in the conduct of their work.

1. Introduction

Situation Awareness (SA) is fundamental to decision-making in many contexts, from individual aviators, to teams in civilian safety and control systems, emergency response, and – our focus - military Command and Control (C2). Various units of analysis have been proposed: the individual, the collective or the systemic. Early approaches studied the state of knowledge of, say, an individual F15 pilot about a rapidly changing environment (Endsley, 1988, 1990; Taylor, 1990) with focus on cognition (Endsley, 1995) across three levels: Perception, Comprehension and Projection. This approach has evolved to addressing teams whose SA is recognised as critical for performance (Fiore and Salas, 2004; Shu and Furuta, 2005; Chiappe et al., 2014), particularly for dynamic and complex situations (Burke et al., 2006; Stachowski et al., 2009). Here 'team SA' is based on either aggregation of individual SA measures (Rentsch and Klimoski, 2001) or notions of 'shared SA' where overlaps (often represented using a Venn diagram) in the SA of individuals for overlapping requirements (Endsley and Jones, 1997) are identified. However, modern technology now offers the promise that distributed organisations, or even 'virtual teams', may be as effective as close knit teams of collocated members. Such arrangements are truly *socio-technical systems* (Ropohl, 1982; Clegg, 2000) where humans and technological components interact through integrated social and technical processes. An alternative approach, the Distributed SA (DSA) model, takes this dimension as its *raison d'etre*, (Stanton et al., 2006). DSA sees cognition as not purely "in the head" of an operator but jointly held across system components using Hutchins (1995) distributed cognition, manifested through a "computational ecology" of tools. Here, SA is *emergent* in systems comprising interacting human and technological agents (Stanton et al., 2006; Salmon et al., 2009, 2010; Neville et al., 2016). DSA has an associated data collection method (Walker et al., 2006) known as Event Analysis for Systemic Teamwork (EAST) which links with an earlier 'ecological' approach (Smith and Hancock, 1994) emphasising the dynamical nature of the environment and the requirement for the human to adapt – see also (Plant and

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http://dx.doi.org/10.1016/j.apergo.2017.02.002
0003-6870/

Stanton, 2016). There are clear distinctions between these models (Endsley, 1988; Adams et al., 1995; Salas et al., 1995; Banburry et al., 2004; Houghton et al., 2008; Salmon et al., 2010, 2012; Walker et al., 2010; Hew, 2011; Neville and Salmon, 2016). Recently, however, a special edition of the Journal of Cognitive Engineering and Decision Making (JCEDM) brought together these and other perspectives revealing agreement around a number of points: operators do not, nor need not, progress *sequentially* through the levels of SA; goals – and not just bottom-up 'data' - may influence situation assessment; cycles or more complex dynamics and the environment are fundamental; and SA resides across human and long term memory, *and* in technological interfaces (Endsley, 2015; Stanton et al., 2015; Klein, 2015). In this paper we further bridge the gap between the 'three levels' and 'distributed' approaches and propose an empirically based unified model for SA.

To return to C2, military definitions of this term refer to the means of legal delegation of decision making *through an organisation* for the planning and execution of missions. In the military, business (Williams, 2013) and even information management communities (Dumbill, 2012) a popular dynamical model for C2 is the Observe-Orient-Decide-Act (OODA) loop. The model was first articulated by US Air Force Colonel John Boyd (1987) for individual fighter pilots but is applied quite pragmatically now to whole organisations – where many individuals undertake their own OODA loop and where an organisational level OODA emerges (Osinga, 2013; Dumbill, 2012). We posit that the OODA and Endsley models are self-evidently related insofar as the latter, in its broader articulation (Endsley, 1995), places the three levels of SA as a feed into *decision making*, and then the taking of *actions* which in turn change the environment that informs the SA (the model also incorporates factors such as system capabilities, interface design, automated activities, long term memory storage and goals and objectives). OODA is also elaborated by the Perception-Action cycle of Neisser (1976), which is used in the DSA literature and underpins the approach of Smith and Hancock (1994). The compactness of the OODA model integrates SA into decision-making: there is no 'OO' without 'DA'. Note also a scientific definition of C2 (Pigeau and McCann, 2000) defining Command as "the *creative* expression of *human* will necessary to accomplish [a] mission" (our emphasis), confirming the importance of the human – as a decision-maker – in generating the *purposefulness* of SA. Pigeau and McCann then define 'C2' as the achievement of *common* intent for coordinated action, emphasising the contributions of the many to an outcome. Thus C2 encapsulates the notion that *different members and/or teams may be responsible for different parts* of the organisational OODA cycle. To this end, seeing SA as the 'OO' steps of Boyd's cycle (as already realised by Endsley and Jones (1997)), we seek a model that can measure the *flow of SA* through an organisation.

We call our unification the Situation Awareness Weighted Network (SAWN) model. It takes into account individual, team and distributed situation awareness and enables understanding of SA flows in the conduct of C2. It is a *model* because it is a representation of reality (Wartofsky, 1979) where objects and states of the world are mapped. In the SAWN model, elements of a graphical representation are mapped as follows: people and information objects to nodes of a network, relationships to links, and levels of SA to numerical weights or colours or line thickness. We developed the model in the course of an empirical study of staff[1] of a headquarters in the Australian Defence Force (ADF), where an integrated up-to-date representation of operational information (FM 3-0, 2008), referred to as a Common Operating Picture (COP), is maintained by the personnel for the attainment and promulgation of SA between tactical, operational and strategic command echelons. The staff, who are either shift or day-workers, use different systems, visual displays and interactions as sources and sinks of information. The COP captures SA to enable coordinated responses to two quite different contexts: for routine reporting of activity in ongoing Areas of Operation, which we refer to as the 'steady-state' Baseline, and the response to unexpected 'crises' requiring rapid coordination of military assets to support civilian activity for search and rescue or disaster relief and/or application of military force. The SAWN model itself and aspects of the method[2] have been presented before in (Ali et al., 2014). In this paper we present for the first time the survey questions, and analyse the flow of SA and quantify the 'value-add' of military staff tasked with the provision of SA. This is particularly useful in resource constrained environments where the role of every staff unit in a headquarters, rather than on a 'front-line', may be subject to scrutiny and rationalisation.

In what follows, we provide further detail on the dominant SA models mentioned above, explaining their aspects relevant for SAWN. We then elaborate on the data collection method. The intent of this paper is to explain the model and the method used; individuals, their specific roles, units and their inputs and outputs are not identified.[3] However, we present an aggregation of the data set collected in the study such that its broad characteristics are evident, thus enabling reproducibility of the representations we show. We then show how insights into the effectiveness of the generation of SA by a distributed system of people and tools can be gained from the resulting SAWN analysis. Specifically, we empirically show how SA flows through this organisation. We conclude with a discussion of the broad applicability of the approach. The detailed survey questions and large scale versions of diagrams are relegated to appendices.

2. Theory: unifying SA models

2.1. Individual SA

The three Endsley levels can be further elaborated as follows: SA Level I is where data is merely perceived, without further processing; Level II involves interpretation of Level I data, enabling understanding of its relevance in relation to tasks performed and goals to be attained. This is where an operator forms a holistic picture of the operational environment and comprehends the significance of objects and events in that environment. Based on a combination of Levels I and II, together with their own experience and grounded knowledge - or *mental models*[4] - operators may then forecast likely future states for the situation giving Level III (Endsley, 1995, 36; Endsley, 1987, 1988, 2000).

The main measurement technique here is the Situation Awareness Global Assessment Technique (SAGAT) where 'freeze-probe' techniques are applied to test operators' knowledge of things taking place during a simulation. Other measurement methods, focused on the individual, but loosely or independent of Endsley's

[1] The term 'staff' describes the individuals and/or positions within a *particular* unit or branch of the organisation, and 'staffs' refers to a collection of individuals or positions from a variety of units within the defence force. When referring to the *abstraction* of the staff in a model, such as a network diagram, we will refer to them as 'agents'.

[2] Much like EAST is the method associated with DSA, but we use the same name 'SAWN' interchangeably for model and associated empirical method.

[3] Participation was voluntary with participants signing a consent form explaining protection of the data and how the research would be used, consistent with Ethics in Human Research guidelines.

[4] Endsley's earlier papers use the construct of schema theory (Endsley, 1988, 1990).

model, are: the Situation Present Assessment Model (SPAM) where probes are administered in 'real-time' (Durso et al., 1999); the Situation Awareness Rating Technique (SART) eliciting subjective assessments of SA and usually administered post trial (Taylor, 1990); and observer rating where domain experts observe and rate participants performing a task under study. Because of this reliance on subject matter experts and being rather intrusive, this latter method is more suitable for assessing SA in stable environments. For the other method, dynamics can be represented in simulations, but SA-related elements must be pre-defined – namely to allow 'ground truth' to be known (Salmon et al., 2009; Saner et al., 2009).

We have already mentioned 'team SA' as a generalisation of individual SA, either by aggregation or in terms of shared/common SA (Endsley and Jones, 1997). Shared mental models (Artman, 1999; Fowlkes et al., 2000; to name a few) also play an important role in this approach. However, presaging the DSA model, the Coordinated Awareness of Situations by Teams (CAST) approach (Gorman et al., 2006) identifies that common and valued goals may need to change with dynamic environments, and operators may need to modify each other's SA requirements through interaction.

2.2. Distributed SA model

The DSA model (Stanton et al., 2006) uses the network paradigm drawing on Social Network Analysis (SNA) and Network Task models. SA involves interactions between human agents via a *social* network, between technological artefacts and concepts through a *propositional* network, and between tasks and the information required to perform them connected in a *task* network. Noting that SNA is a respected method for analysing SA in its own right (Bourbousson et al. 2015), empirically the object of DSA is to collect data about three types of networks. Propositional networks are created by defining the concepts or information elements and their relationships, expressing what needs to be known for the performance of tasks (Anderson, 1983; Crandall et al., 2006; Stanton et al., 2006; Salmon et al., 2009, 2010; Houghton et al., 2008). The information elements for a given task are obtained in EAST (Walker et al., 2006) either by observation or via the Critical Decision Method (CDM), a strategy to elicit expert knowledge for decision-making using cognitive probes (Klein et al., 1989; Hoffman et al., 1998). Propositional networks thus build a team SA picture from all the pieces that individuals hold. Such networks also relate to schema theory. In Stanton et al. (2009) it is suggested that propositional networks provide insight into phenotype schemata, for example the local state specific routines by which human agents interact with devices and displays for the access of SA. With sufficient documented examples of these, the genotype schema may be understood.

2.3. Why a unified model?

Our earlier characterisation of the work conducted in the headquarters' unit of our study shows that the staff, individually and collectively, actively engage in understanding past, present and future states of the variety of actors in areas of operation. Information they receive comes from a range of distributed sources. The staff themselves are distributed – in different teams and in different locations. The different teams correspond to designation under the Common/Continental Joint Staff System (CJSS) where (JFSC, 2000) 'J3' are operations staff, controlling movements of tactical units in areas of operations, and 'J2' are intelligence staff monitoring possible threats in the same or adjacent areas. These same staff issue routine briefs, drawing from the COP as well as other displays or devices. These information systems are, themselves, complicated in their own right often automatically drawing upon inputs from multiple components that may be rightfully analysed as an information architecture. In the context of our study, the displays accessed by the J2 and J3 staff do not automatically interact with each other except via a human interface; of course future autonomous systems may be quite different in this respect representing distributed cognitive systems in their own right. Such interactivity may be represented in SAWN, to which we return in the conclusion.

Returning to the human subjects, the J3 watch staff are also responsible for initial responses to events while day-staff analysts in the J2 provide deeper examination of events. Evident then is the distributed property of the headquarters, in terms of staff interactions within teams and across a wider community of people and technology systems, and with the products they generate; hence the DSA model is highly applicable. So too was articulation of the cognitive effort of individual staff in analysis of sensor data required to *understand and anticipate* actions of entities in the environment in order to build the COP. Furthermore, staff consciously seek to *value-add* by integrating information and forecasting. Therefore, the Endsley model is also apt in describing the daily work of the study participants. In addition, the headquarters in question must confront a diversity of 'C2 problems'[5]– from state and non-state based adversaries to the consequences of a natural disaster. It must therefore display a diversity of 'C2 approaches'– from a traditional hierarchy to complete network centricity (Alberts et al., 1999). This diversity warrants a fusion of the two dominant models of SA discussed earlier.

Proposals for unifying the Endsley and DSA models have already been reported in the literature. For example, while addressing the integration of human and machine elements in SA, Hew (2011) proposed a model built on Time Coloured Petri Nets but which are built on an analyst's understanding and *interpretation* of the application domain (for example, sensor-shooter systems and interactions in coordinated fires) thus introducing a degree of subjectivity and manual effort in building visual representations. These concerns motivated our approach in developing a model where 'social' and 'information artefact' interactions are captured *and represented together* with the same data collection instrument that then *automatically* generates the network visualisations. This is not to deny analyst subjectivity in SAWN: this is concentrated – with deliberate effort to minimise it – in the data collection *preparation* step of the method.

2.4. Situation Awareness Weighted Network – the SAWN model

Traditional SNA captures the interaction patterns of individuals (nodes) in a transaction (links) that may be purely social or business in nature. SAWN expands on this by including in the same network nodes representing information artefacts, such as documents, PowerPoint slides, signals and the whole or parts of system displays used. Individuals thus transact information between themselves and/or information artefacts. This means that the 'pure' social network is embedded in this larger socio-technical network. Tasks may be added as extra nodes to provide context to the network diagram. In distinction to DSA, SAWN sees *weights* applied to the links – as line thickness or, in our case, colours – where the *weights indicate the SA level, according to the Endsley model*. The networks are semi-bipartite in that information artefact nodes do not – of themselves – directly interact with each other (this may be different if these nodes were components of a more sophisticated computational system) while human agents do. Finally, we can

[5] See the distinction between C2 'Problem' and C2 'Approach' of the NATO (2006) C2 reference model.

distinguish separate networks for the pulling (or consumption) and pushing (production) of information. A simple example of SAWN is shown in Fig. 1, where individuals A, B, C, D interact with each other and with information artefacts X, Y, Z, W. We may represent Endsley's three levels through the colour scheme Green = Perception, Blue = Comprehension and Red = Projection. Here we depict a sequence of transactions: A draws on information product X to deliver low SA (green line) to B encoded in Y, but B correlating this with separate information product Z (also low SA) delivers higher SA to C (blue line) who finally, through access to artefact W with higher SA value (blue line), provides the highest SA level to D (final red line). SA may be said to flow. In particular, value has been added through the transactions.

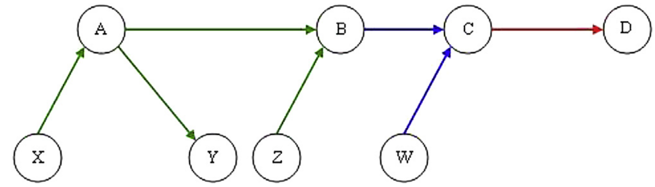

Fig. 1. Representation of a Situation Awareness Weighted Network where circled letters represent individual agents (A–D) or information artefacts (X–W), and directed links represent pulling from or pushing to of information, and three distinct colours represent the Endsley SA level: Green = Perception, Blue = Comprehension, Red = Projection. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

We emphasise that the SA rating of an interaction may be entirely subjective precisely because of the individual human dimension of SA. In Fig. 1, the labelling of the link from B to C as ‘Comprehension’ may be based on the intent of B in communicating to C, but the latter might not extract the same content from the interaction (and may rate it as Perception, turning the line to Green). Alternatively, the rating may be based on what C receives from the communication. Such divergence may be represented as an additional link or applying different colours to the source and destination ends of the same line. Above all, this aspect captures the reality that SA is not a simple mechanical aggregation of individual SA cognitions: each individual at a node of the network here (such as C) will uniquely ‘integrate’ the SA of the separate links converging on them in achieving their output. Naturally, links may also be weighted, for example with line thickness, according to the frequency of use. However, in our case study, due to the sample size, this feature will not be employed.

There is, therefore, the capacity in SAWN representations to capture divergences in perspective from the many agents in the system. Seeing SA levels as incremental gradations of ‘value’, the method may identify paths through large complex networks representing chains of value creation through a socio-technical system, some steeper (higher value created through fewer steps) than others. Finally, as this discussion suggests, we may distinguish between pushing and pulling of information via the same or different networks. Indeed, to avoid clutter, we later separate push/pull networks.

3. Method: the study approach

The overall study approach is depicted in Fig. 2 with key components explained below.

3.1. Data collection – the SAWN method

We developed a survey with statements designed to progress incrementally through Endsley's SA levels (3–5 statements corresponding to each of Endsley's SA levels). The distributed nature of SA was captured through statements about use/produce and interactions for a respondent's own and others' benefit. The survey comprised 24 statements relating to each of Products (P) and Organisations (O): the former (P) probed either the SA provided in information artefacts that a staff member prepares for others or SA gained from those for one's own benefit, the latter (O) elicited the formal and informal interactions with groups and/or individual agents in external organisations for building own and others' SA. The survey design is depicted in Fig. 3 and the statements populating the data collection instrument are given in Appendix 1.

To illustrate the tool, consider an operator who observes an aircraft track using an ATC display. At Question Q1a (Appendix 1) they would identify that display by entering its name (or selecting it from a drop-down list if choices are pre-populated in a spreadsheet) to indicate that the display “draws their attention and identifies” the aircraft. If the display provides no further information assisting the operator – for example, no history of tracks is accessible – then the link between the operator and the display acquires the raw value 1. If history is available that builds further understanding then the raw value for that link becomes 6, within the Comprehension sub-levels. At a higher level, consider a weather forecaster who would prepare a forecast for some geographic area. They would respond to Q11b (Appendix 1) in order to indicate they produce the forecast enabling others to anticipate effects of the physical environment in the next 36 h. Thus the link between forecaster and their forecast is assigned a raw score of 11. The more thoroughly the tool is prepopulated with choices of individuals, units, information objects or displays, the more automated the process from data entry to network generation may become.

This tool may be regarded as analogous to SAGAT but with two advantages. Firstly, it is a more graduated approach through the SA levels allowing greater fidelity. Secondly, seeing the SA levels as part of the OODA model, it may be extended further to cover ‘decision’ and ‘action’ questions. We return to this in the conclusions.

Two sets of data were collected representing different operational conditions. For the Baseline (steady state) snapshot, the survey was administered electronically via an Excel attachment to an email. Staff were asked to reflect on and briefly describe the most significant events of the past 36 h from the time of answering the survey while considering their anticipated activity for the next 36 h. They were then asked to choose from a drop-down list up to four products and organisations, respectively, in order of relevance to the SA level. Samples were gathered across all shifts over the course of one week. For the Scenario (crisis) snapshot, staff were individually interviewed. Following an immersion in a set of events and sequence of tasks, participants were asked to select products they would use/produce (pull/push) and to nominate organisations they would interact with to achieve their SA or support someone else's SA. The set of events was derived from a separate Scenario workshop explained below. For the Baseline survey, 38 (J3: 17; J2: 21) responses were received. The Scenario interview involved 27 (J3: 15; J2: 12) participants.

3.2. Developing a scenario and task model

In order to analyse the generation of SA in a possible future Scenario it was necessary to understand what tasks, information and intelligence are required. Thus we developed a scenario covering a hypothetical event with a timeline, a range of constraints and assumptions; the event itself combined separate real world events with which the participants had significant experience – only the coincidence of these was itself novel. The constraints were to push the boundaries of the study participants such that the tasks and information needed through the scenario were non-routine. We conducted a knowledge elicitation activity involving military subject matter experts drawn from planning, operations, intelligence and single-service units in the headquarters to delineate the tasks, information and intelligence requirements throughout the Scenario. A combination of two dialogue methods, Future Backwards (Cognitive Edge, 2013) and the aforementioned CDM, was used to elicit these requirements. More detail on the workshop is given in (Ali et al., 2014). The workshop outputs included the flow of some 80 tasks, captured in workflow modelling software, and lists of decisive points and 34 (COP) information requirements for the crisis scenario. The sources/producers of this information were then separated into internal and external Providers. During the Scenario interview, participants were shown a summary of the Scenario and COP needs via a chart covering four decision points.

3.3. Activities vs tasks

To simplify network diagrams we aggregated the 80 'crisis' tasks into two broad activities, Crisis Action Planning (CAP) and Intelligence Preparation of the Battlespace (IPB). These are broadly similar between Australian and US military forces – see, for example, US Department of Defence publications JP (2011) and FM 34-130 (1994). CAP is 'Planning while Executing' for J3 staff to deal with rapidly evolving events. A rapid assessment of the situation is required, calling for reporting on the status of force elements in the relevant area. Existing Contingency Plans may be adapted to draft Courses of Action (COAs) whose number depends upon the time available. These alternatives are presented to a Commander for decision. Operational Orders (OPORDs) are then written and promulgated to assigned forces for execution. The phases of CAP are sometimes labelled 'Assessment', 'COA Development', 'COA Selection', 'Execution Planning' and 'Execution', but any one of the intermediate steps may be compressed under time pressure and each instance of CAP may differ from others. Contrastingly, IPB is a J2 staff process that supports deliberate, contingency-based or time-compressed Planning. Steps include describing the 'Battlespace' physical, social, political, diplomatic and technological characteristics, sources of potential threat and their likely COAs. In the context of CAP, IPB is a continuous process. Depending on time pressure, the Blue Force COAs arising from CAP may be tested (or 'war-gamed') against potential Red Force (enemy force) COAs.

4. Data, analysis and discussion

4.1. Classifying nodes

From the survey data we identified a range of 'organisation' and 'product' nodes for a prospective SA network. We list these, after some aggregation, in Table 1.

4.2. Link weighting and aggregation scheme

Each link between an individual and a product in response to a specific statement was assigned a numerical weight, with value one for the first statement at the lowest Endsley level, building up to higher raw values as explained earlier. The raw value is then rescaled according to the scheme in Table 2. The rescaling weighting scheme was chosen such that nomination of a given individual or product in answer to multiple statements at lower Endsley levels did not lead to the same or greater *aggregate* weight if that agent or product was elsewhere nominated in answer to a single statement at a higher Endsley level. Thus, even if a product was nominated in answer to all statements at Endsley Levels I and II (aggregate weight of 66.0), its weight would still be less than if it was nominated by someone else just once as Level III (minimum of 68.0). Next, the results for multiple agents were aggregated into the one 'organisation' node by simple averaging where people rotated into the same specific role in a shift roster or to avoid identifiability of individuals in Table 1; because of our sample size, there was little value in more sophisticated descriptive statistics. Here we summed the weights from those agents being aggregated who have nominated a specific product or organisation and divided by the number in that aggregated node that nominate the product/organisation.

4.3. Colour scheme

As explained, data was captured with 12 statements each for

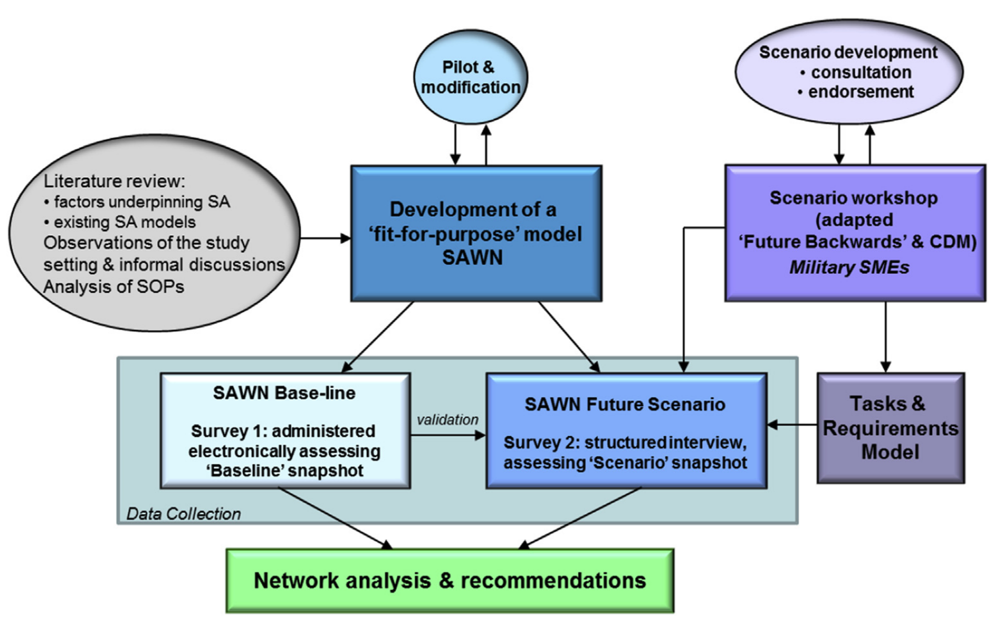

Fig. 2. SAWN Study approach.

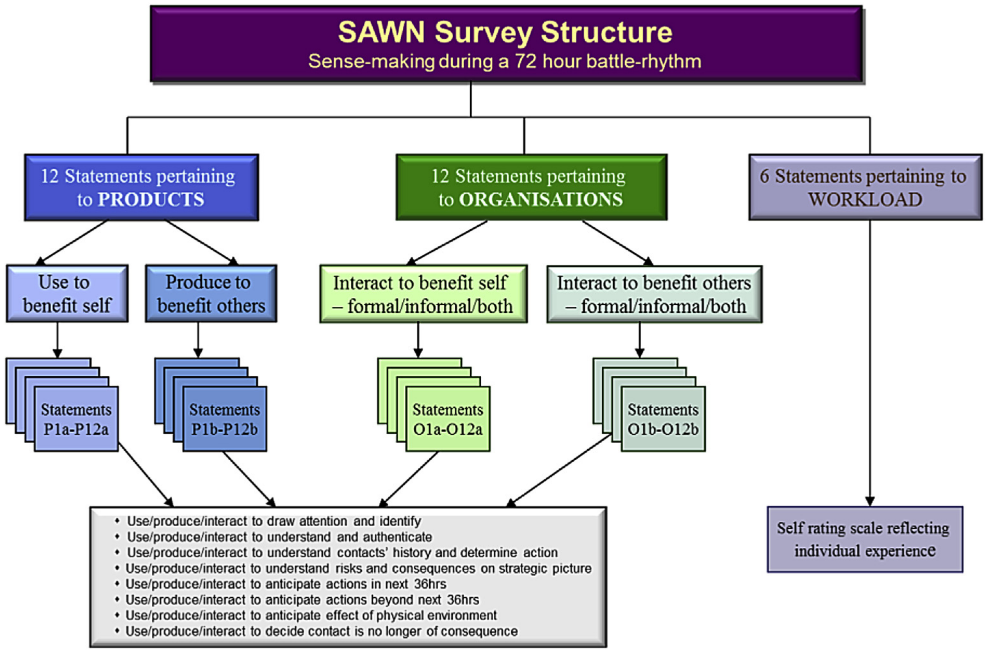

Fig. 3. Structure of the SAWN survey.

Products and Organisations, refining the three Endsley levels into finer gradations. For clearer visual representations we aggregate the data according to the nodes in Table 1 and combine the weights assigned to the three Endsley levels, as shown in Table 2.

For later use, we also divided the range of average weights of links into 13 histogram bins according to the scheme in Table 3.

4.4. Networks

We present the resulting SAWN diagrams (generated using *NetMiner*™) shrunk in size but placed side by side to provide a comparison between 'pull' and 'push', and between Baseline conditions, Fig. 4, and Scenario conditions, Fig. 5. In Appendix 2 these diagrams are expanded in size. Note that the separation of 'pull' and 'push' provides best readability of the networks; early versions of these with push and pull combined were trialled with military decision-makers with limited success. The clean separation in Figs. 4 and 5 provided greatest readability for analysts and military alike.

To allow the interactions between the *sampled agents* (purple nodes) to be most visible we arrange those nodes on the *outside*, products (green nodes) interior to them and external (orange) nodes at the centre of the network. Colours for nodes and links are as explained in Table 3. *For pull networks the arrowhead is on the node drawing the information with the colour indicating the SA level attributed to the information by the pulling (destination) agent; for push networks the arrowhead is on the destination node with the colour indicating the SA level attributed to the information by the pushing (source) agent*. Occasionally links will have arrows at both ends with two colours indicating that (for pull networks) both nodes draw information from each other but where each attributes different SA value to the information from the other.

At a broad level, the networks provide an impression of the rich 'ecology' in the sense of Smith and Hancock (1994): agents interact variously with their near colleagues and distant external actors, while seeking to achieve goals within the broadly characterised tasks of CAP and IPB. Additionally, no single agent covers the entire SA range; rather the SA level is contingent on interaction with other agents. For both Baseline and Scenario there are more links for pull than push indicating that our study agents are genuinely *consolidating* information. The pull data is, generally, at lower SA levels and push is at higher levels: there are more green links in the left hand networks and more red links for the right hand networks. Thus the agents, through the consolidation of information, are *value-adding* SA. This will be quantified shortly. We also observe in the networks that higher ranked agents (OJ3W1, OJ2W1) generate higher levels of SA than lower ranks, and in turn this SA is provided to senior officers (OCmnd), consistent with the military hierarchical design of the headquarters. The self-loops in both Figs. 4 and 5, show SA passed between individuals in the same role through a shift handover or within teams.

The network diagrams also expose differing, even conflicting, perspectives on the SA value that individuals or products provide. For example, in the Baseline pull data (Fig. 4, left) we observe that the links between OJ2W1 and OJ2W2, and OJ2W1 and OJ3W1, each change colour. Thus agents in OJ2W1 receive SA at a Perception level from their subordinate OJ2W2 (the green arrowhead) and agents in OJ2W2 receive Projection level SA (red) from their superior officers in OJ2W1, a reasonable state of affairs. Contrastingly, agents in OJ3W1 receive Perception from OJ2W1 while agents in the latter receive Comprehension from the former. Looking at the out/push data for Baseline (Fig. 4, right) we see red arrows between OJ2W1 and OJ3W1; both believe they have pushed Projection levels of SA to the other. However, in the Scenario (Fig. 5, left) this is quite different; agents in OJ3W1 *expect* to receive Projection from OJ2W1, while agents in the latter only expect Comprehension from the former.

Such networks enable a visual articulation – and further, through SNA metrics, a quantification - of the degree of 'team SA' in this headquarters through the degree of clustering or community structure in the graph. At the level of unweighted graph, the networks show strong 'teamwork' within the J2 and J3 staff, with a lower level of teamwork across the two branches. However, through the overlay of SA weights, the exposure of conflicting SA expectations by the leading staff in the respective sections shows where the weakness in the 'team SA' across the entire watch staff

Table 1
Nodes in the network after aggregation of raw data; italics indicate organisational nodes that were sampled.

Organisations	Characterisation	Products	Characterisation
OCmnd	Commander, or function/section Heads	Pemail	Formal email that documents information (rather than ad hoc communication)
		Pweb	Documents acquired through intranet
		Pbrief	A fused brief from J3 and J2 staff (see below)
		PCOP	Parts of a COP maintained by J3 and J2 staff
OJ3W1	Senior Officers in J3 Watch	PJ3Brief	Routine Briefs from J3 Watch staff
OJ3W2	Junior Officers/NCOs in J3 Watch	PJ3Ord	Orders issued by J3 Watch staff
OJ3WS	Support officers in J3 Watch		
OJ3S	Support officers in J3	PRpt	Formal Reports by military staff
OJ2W1	Senior Officers in J2 Watch	PJ2WBrief	Routine Briefs by J2 Watch staff
OJ2W2	Junior Officers/NCOs in J2 Watch	Padhoc	Ad hoc document or PowerPoint slide to capture ongoing events
OJ2A	Analysts in J2 Staff	PJ2AnBrief	Analysis Brief by J2 staff
		PThrAss	Threat Assessments
OJ2S	Support officers/NCOs in J2 staff	Popen	Open source information – internet
OStrat	Strategic Level Staff external to the HQ	Penv	Reports on physical environmental conditions
OExt	Organisations external to Australia	PExt	Reports from organisations external to Australia
OInt	Other intelligence organisations	PInt	Reports from other intelligence organisations
OJTF	JTF HQs	PJTF	Brief or formal signal from JTF HQ
OSS1	Single Service (Army, Navy, Air Force)	Pdef	Signals from Single Service units
OWOG	Non-defence government departments	PWOG	Reports from non-defence government departments

lies. This analysis may be extended to see the information objects as members of the 'team' now, and how they knit smaller team structures together.

For example, in Fig. 6, we extract sub-graphs revealing interactions with specific information artefacts for the J3 Brief and COP artefacts for Baseline-Pull. We observe the quite different levels of SA lodged in the information objects – the J3 Brief with Perception, and the COP with Comprehension. The other dominant effect in these sub-graphs is that Projection is very much a property of the human interactions.

4.5. Quantitative analysis – SNA metrics

SNA allows visual impressions to be quantified. Standard are out/in-degree centrality and node betweenness centrality (Wasserman and Faust, 1994), where higher centrality indicates major sources and sinks of information. Such metrics are already standard in DSA (Jenkins et al., 2012). The normalised measures, for each node n, are defined by the unweighted-directed adjacency matrices (Chung, 1997):

$$C_{out}(n) = \frac{1}{N-1}\sum_{j=1}^{N-1} A_{n,j}^{(out)}, \quad C_{in}(n) = \frac{1}{N-1}\sum_{j=1}^{N-1} A_{n,j}^{(in)}.$$

Betweenness centrality relates to paths between non-adjacent nodes (k, m) where *other nodes* on the path potentially control the interaction between k and m (for example between the most junior member of staff and the Commander in a hierarchy). Nodes with the highest betweenness centrality enjoy the most influence within the network (Friedkin, 1991). Labelling $g_{k,m}$ as the number of shortest paths between nodes k and m in the network, and $g_{k,m}(n)$ as the number of those that travel through node n, the normalised betweenness centrality for node n in an unweighted and undirected graph, is given by:

$$B(n) = \frac{2}{(N-1)(N-2)}\sum_{1<k<m<N}\frac{g_{k,m}(n)}{g_{k,m}}.$$

Applying this to the *unweighted* data (computed using *NetMiner*™) we obtain the values given in Table 4.

Focusing on degree first, the node 'Popen' (representing an aggregation of a range of open source material on the internet) is the highest information object from which information is pulled; being a 'passive' source it has zero in-degree measure. This occurs for both steady-state baseline conditions and in the crisis scenario. The basic briefing products are the significant push nodes – but only for *baseline* conditions. In the crisis context, other types of formal reporting become more important than information objects: the major sources of information here are the *humans* in the J3 watch positions. For example, J3W2 and J3W1 figure highly for both in and out-degree measures. For betweenness, we find that J3 support officers and higher ranks of the J3 watch are significant in *passing information*. The former officers play the role within the watch unit, while the latter act as a transfer point between the two watches (J3 and J2) and higher command. Thus, the coincidence of J3W1 having high degree and betweenness centrality is that these officers are critical in fusing information collected across diverse sources but to enable the decisions of higher command.

To validate that these networks represent high centralisation it is helpful to compare the degree distributions of the Baseline state and Scenario contexts with a number of random graphs with comparable numbers of nodes, links or average degree. For example, the Barabasi and Albert (2002) algorithm generates networks with a scale-free property, namely a power-law degree

Table 2
Colour scheme for nodes and links in SAWN diagrams.

Node	Node Colour	Link Endsley Level	Link Colour
Sampled organisations	**Purple**	I: Perception (Questions 1–3) Weights: 1.0, 2.0, 3.0	**Green**
Non-sampled organisations	**Orange**	II: Comprehension (Questions 4–8) Weights: 8.0, 10.0, 12.0, 14.0, 16.0	**Blue**
Products	**Green**	III: Projection (Questions 9–12) Weights: 75.0, 82.0, 68.0, 82.0	**Red**

Table 3
Distribution of weights according to bins. Bins 1–3 = Perception, Bins 4–10 = Comprehension, Bins 11–13 = Projection.

Level of Bin	Weight Range
1	0–2.66
2	2.66–5.33
3	5.33–8
4	8–16
5	16–24
6	24–32
7	32–40
8	40–48
9	48–56
10	56–66
11	66–162
12	162–260
13	260–358

distribution ranging from one highly connected (and therefore central) hub to a large number of singly connected nodes. The algorithm is based on preferential attachment where at each step a new node is connected to m existing nodes proportional to the number of links of existing nodes. Here we consider a total number of nodes for the scenario network and trial $m = 3$ and $m = 4$ averaging over 1000 instances in each case (noting that scale free graphs are often more relevant for vastly larger networks). Another real world network is the small-world graph, here generated by the Watts and Strogatz (1998) algorithm where a regular ring graph is rewired with some probability p of a link being replaced; $p = 0.2$ provides for a similarly sized graph to the scenario case but reflecting the small-world property. Each of these is a heterogeneous graph. A contrasting example is the classical Erdös-Renyi uniform random graph, where we keep the same number of nodes and average degree of the Scenario case network.

We observe in Fig. 7 that both the Baseline and Scenario networks show a significantly higher degree for the hub node compared to the BA cases, supporting the conclusion that indeed the military cases are highly centralised networks reflecting the hierarchical C2 arrangements. Unsurprisingly, the hub node is the senior officer in the J3 watch, OJ3W1. We note that many traditional measures of hierarchy in networks fail to distinguish a tree graph from a star or chain as more 'hierarchical' for intermediate size graphs (Czégel and Palla, 2015). We stress that these calculations are illustrative of what SAWN offers computationally – the weighted versions of these metrics are available however we forego analysing them here in order to focus on some novel computational possibilities using the weights in SAWN.

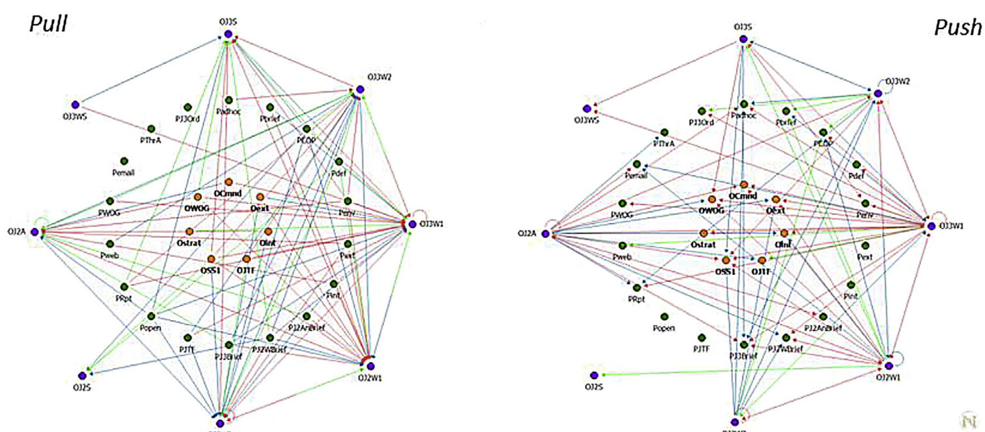

Fig. 4. Situation Awareness Weighted Networks for Baseline activity.

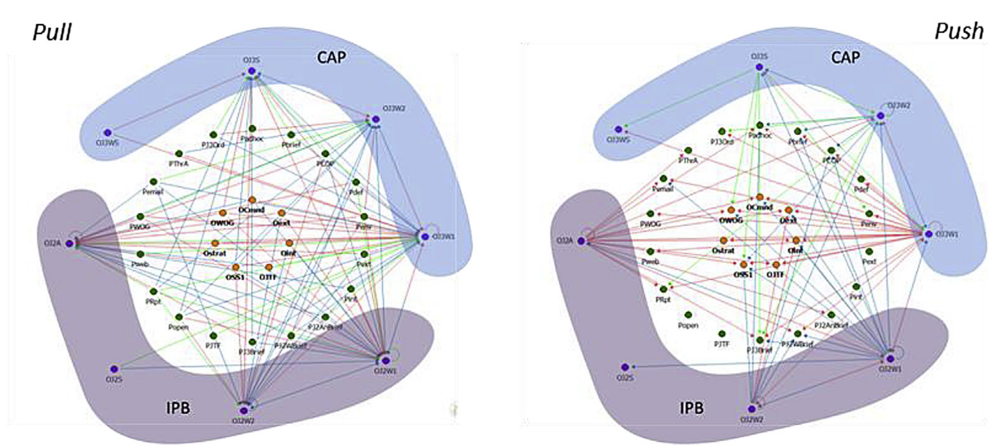

Fig. 5. Situation Awareness Weighted Networks for Scenario activity.

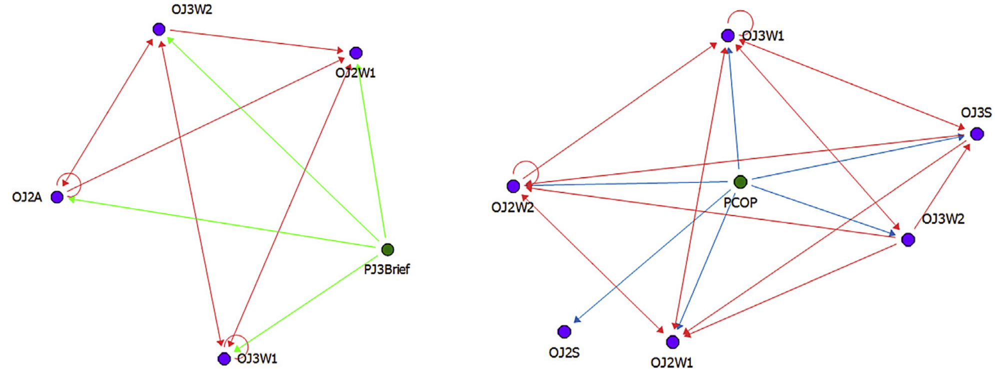

Fig. 6. SAWN Subgraphs from Baseline-Pull data focused respectively on the J3 Brief and the COP information artefacts.

Table 4
Nodes with highest values of degree and betweenness centrality for Baseline and Scenario cases.

	Degree centrality			Betweenness centrality	
	Node	Out-degree centrality measure	In-degree centrality measure	Node	Node betweenness measure
Baseline pull	*Popen*	0.170732	0.000000	OJ3S	0.045528
	OJ3W2	0.146341	0.243902	OJ3W1	0.038211
	OJ3W1	0.121951	0.414634		
Baseline push	*OJ3W1*	0.146341	0.170732	OJ3W1	0.066890
	OJ3W2	0.146341	0.170732	OJ3S	0.048374
	PJ3Brief	0.146341	0.000000		
	Pbrief	0.146341	0.000000		
Scenario pull	*OJ3W2*	0.170732	0.365854	OJ3S	0.029955
	Popen	0.170732	0.000000	OJ3W1	0.024418
	PRpt	0.170732	0.000000		
Scenario push	*OJ3W2*	0.170732	0.390244	OJ3W1	0.021972
	OSS1	0.170732	0.000000	OJ3W2	0.022480

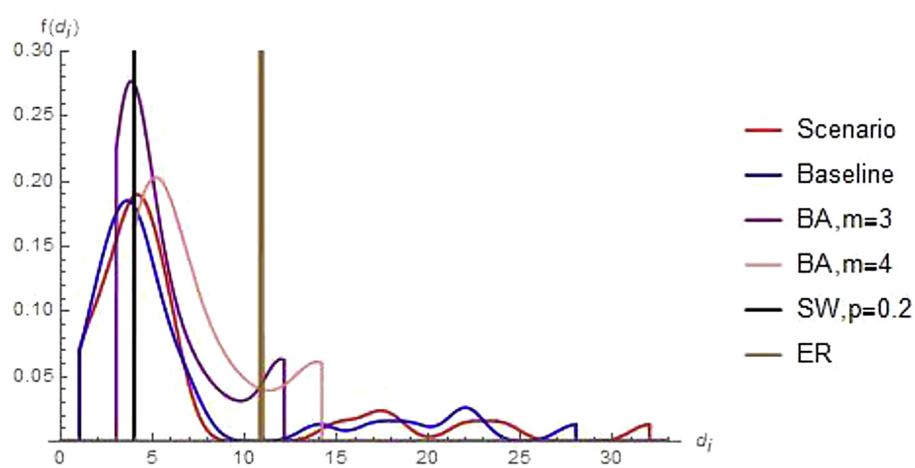

Fig. 7. Degree distribution for the Scenario, Baseline and four other random networks: the Barabasi-Alberts (BA), the Small World (SW), and ER (Erdös-Renyi) networks with same number of nodes as the scenario case. For the four random graphs we average over 1000 instances.

4.6. Quantitative analysis — SA level counts

To measure the degree of value-add we plot a histogram in Fig. 8 of the numbers of links per SA 'sub-level' according to Table 3.

The 'non-linearity' of SA levels is manifest; even within the above view that some staff 'occupy' certain SA levels according to their military rank and function, there is *no monotonic* build-up of SA across the levels. This is partially a consequence of the partitioning of the data, with seven levels assigned to Comprehension but three each for Perception and Projection leading to lower counts in the middle range of Fig. 8. However, even by visual inspection if nearest neighbour bins (for example, sub-levels 4–5, 6–8, and 9–10) were combined there will remain a jump in the count across the SA boundaries: the lowest level of Comprehension/Projection will be higher than the highest level of Perception/Comprehension. We speculate that this pattern may indicate an '80/20' principle: the cognitive effort to go higher within an SA level increases non-linearly after crossing the threshold from one SA level to the next. We nevertheless quantify the trend seen visually earlier: for both Baseline and Scenario, the number of links at low

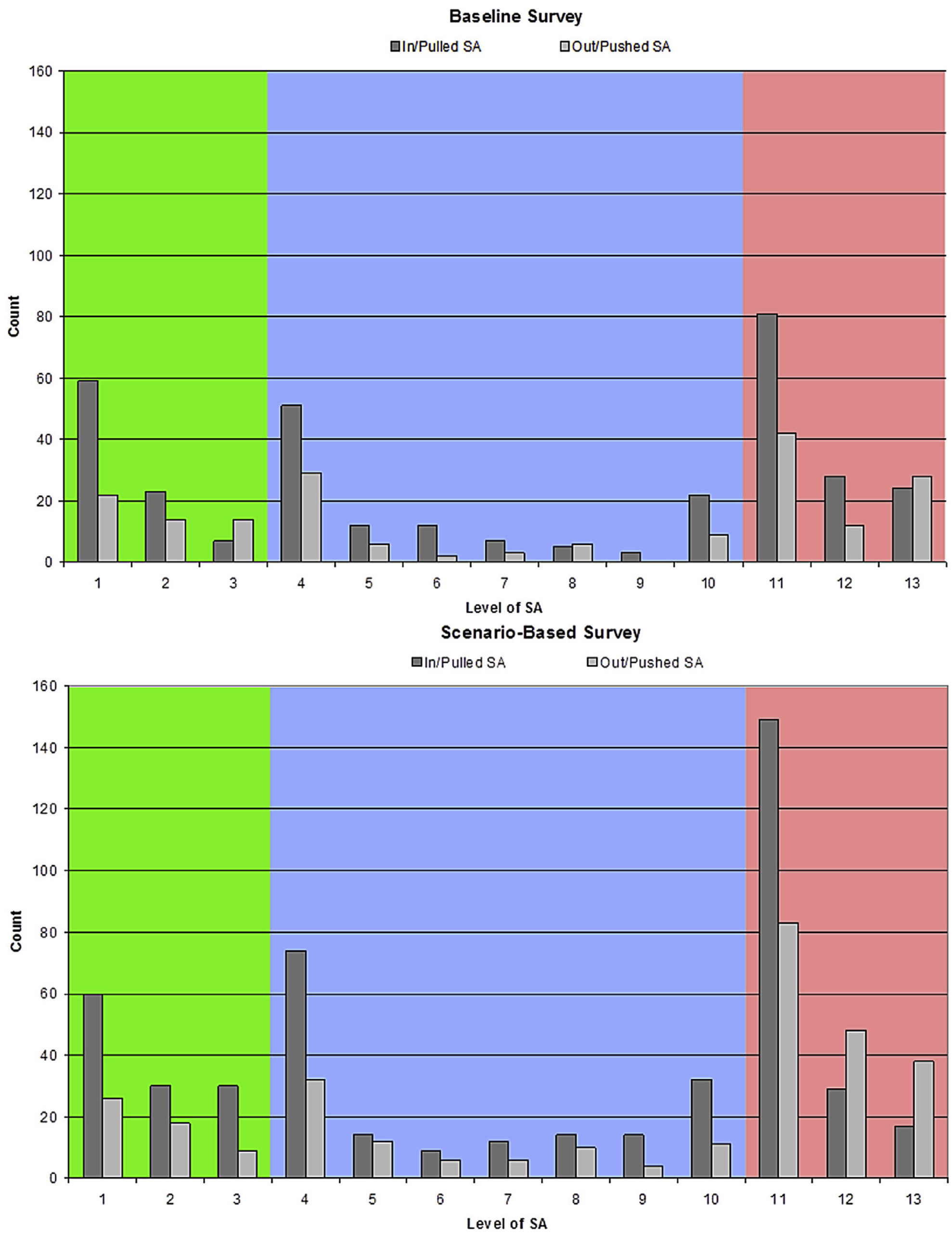

Fig. 8. Histograms of numbers of links per SA level for Baseline (top) and Scenario (bottom) conditions. In (dark grey bars) and Out (light grey) links are distinguished. Also, the backgrounds are coloured according to the three-level SA model: Green = Perception, Blue = Comprehension, Red = Projection. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

levels of SA (green areas) is more for 'pull' than 'push' for levels 1–4, and more for 'push' than 'pull' for levels 12 and 13. Also, the larger number of SA sources for the Scenario is evident, particularly at the thresholds for Endsley Levels II and III; for example, at Level II more than 140 links to sources were identified in the data. This phenomenon of information seeking behaviour during crisis or emergency situations is known as 'uncertainty reduction theory' (Berger and Calabrese, 1975; Afifi and Weiner, 2002). In conditions of high uncertainty and task complexity people seek more information for decision making than for routine tasks and show preference for verbal as opposed to written media (de Alwis et al., 2006).

4.7Quantitative analysis – SA flow

SAWN enables quantification of an SA 'gradient' that generalises 'paths' and 'reachability' in SNA (Wasserman and Faust, 1994). We identify the 'start' and 'finish' nodes of a flow of SA and the paths between them, either through other agents or product nodes.[6] A gradient for the start to finish path may be defined as:

$$\Delta S_{sf}(path) = \frac{1}{N-1}\sum_{n=1}^{N-1}\overline{w}_{i_n i_{n+1}}$$

[6] In these paths we omit the 'self-loops' in Figs. 4 and 5.

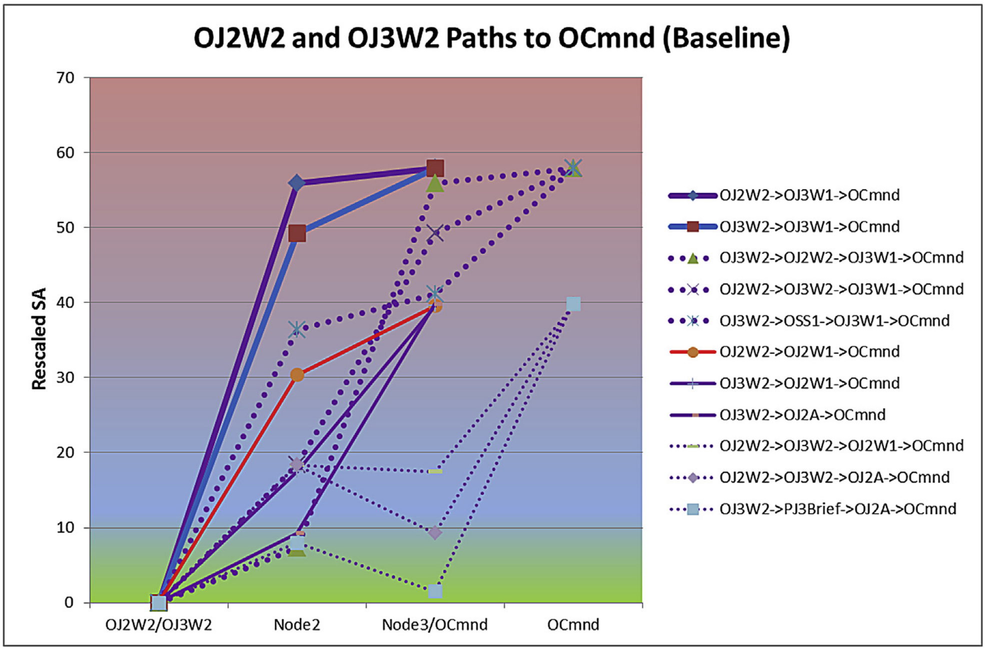

Fig. 9. Paths from low-ranked J2 and J3 watch staff to Command (Baseline). Blue lines represent paths purely within the J3 organisation, red lines those within the J2 and purple lines are mixed paths. Paths with the highest average SA gradients are represented by thick lines and those with lower average gradients by thinner lines. The background colours follow the scheme of Fig. 4 and 5, where Green = Perception, Blue = Comprehension and Red = Projection. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Here we average over both pull and push weights for the N-1 links between the N nodes along the path (including the start and finish nodes); if only push or pull, and not both, occur between a pair of nodes then the full value of the weight occurs. We use the weights assigned via the scheme of Table 2 so that (as before) aggregation does not change the basic Endsley SA levels. However, when plotting the results we rescale these weights back to a linearised scale so that small deviations at high levels of SA are

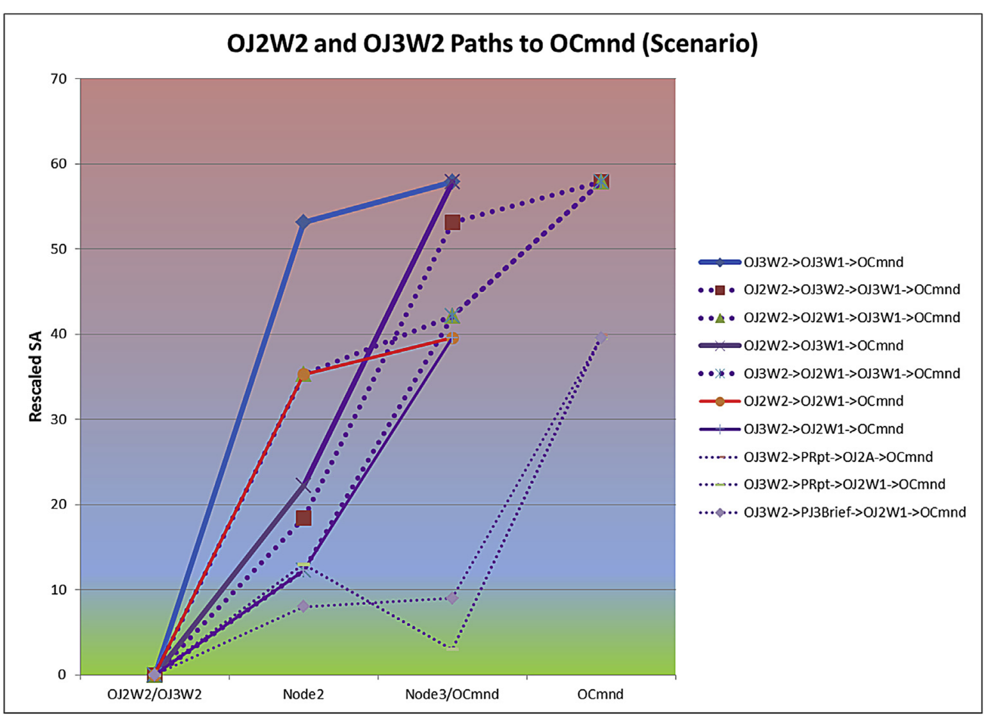

Fig. 10. Paths from low-ranked J2 and J3 watch staff to Command (Scenario), with colour and thickness conventions as for Fig. 9. The two paths OJ3W2->PRpt->OJ2A->OCmnd and OJ3W2->PRpt->OJ2W1->OCmnd are nearly identical and are thus indistinguishable. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

not exaggeratedly large compared to small differences at lower levels.

For example, to compute the SA gradient between the lowest and highest points in the hierarchy we examine the paths between the lowest ranked staff in the J2 and J3 watch and Command. Figs. 4 and 5 show that most nodes have multiple links. As the number of intermediate nodes increases there is a rapid growth in the number of possible paths between the lowest ranked J2 and J3 staff and Command but most of these paths involve links with relatively low levels of SA and ‘revisits’ to nodes already on a given path. Thus, the average gradient of these longer paths is generally lower than that of the best paths with one or two intermediate nodes, on which we focus.

Fig. 9 depicts representative flows of SA along all the two-hop paths (solid lines) and a selection[7] of three-hop paths (dotted lines) for the Baseline case. Fig. 10 similarly depicts flows of SA for the Scenario case. In both figures the order of paths in the legend is from the highest average SA gradient at the top to the lowest at the bottom.

The shortest paths are critical in a crisis. We observe in both Figs. 9 and 10 that for both Baseline and Scenario the highest levels of SA are reached from the lowest in *two hops* from the lowest ranked member in each branch to Command. For Baseline, the fastest and highest increase in SA occurs on a mixed path involving both J2 and J3 staff (purple solid line in Fig. 9). For the Scenario, the steepest path is purely within J3 (solid blue line in Fig. 10). Significantly, for three-hop paths, the lowest overall average SA is generated when a product occupies an intermediate point on the path. *Evidently, human operators invest (deposit and seek) the most SA in their social interactions*. In this case, the relevant operators were geographically collocated enabling such an interaction. In contrast, the lowest of the top three-hop paths shown for the Baseline case involves a geographically separate ‘Single Service’ (Army, Navy or Air Force) agent (OSS1). Indeed, most of the intermediate three-hop paths, apart from those with the three highest and lowest SA gradients shown on Figs. 9 and 10, characteristically involve non-collocated units.

5. Conclusions and future work

We have unified two leading models of SA. We populated the model with data collected in a study in the ADF. This resulted in graphical representations as weighted directed semi-bipartite networks exposing the complexity and non-monotonicity of the process of generating SA in a distributed setting. These representations show behaviour that is consistent with the hierarchical C2 arrangements of our study headquarters and with uncertainty reduction theory. The networks visually and quantitatively demonstrate individual and collective cognitive effort building SA through the organisation, or “value-adding”, to bring information to the point where Commanders can make decisions. The networks, through cluster analysis, may reveal where team work is active and where it is nascent, here (predictably) strong within branches and nascent between (even collocated) branches. In particular, it revealed the nascent C2 relationship between the two leaders of the watches from different branches with recognised mutual dependence on each other for sources and fusion of SA. The analysis also showed the contrasting levels of awareness provided by various information artefacts in different situations. The analysis shows the unique role of the human relationships particularly in a crisis. Analysis of paths between junior and senior staff reveals that, indeed, the former and their immediate superiors enable a rapid transfer and value-adding to SA to enable Command decisions.

More generally, SAWN diagrams and quantitative path analysis can also expose both conflicting perceptions about the value of particular organisational roles or information artefacts, gaps, flows and value-addition of SA vertically and horizontally through organisations. In larger socio-technical systems, where the number of paths through the organisation increases non-linearly with the number of components, such SA flow analysis may determine where efficiencies may be gained but also where important redundancies lie. Similarly, in larger systems the power of cluster analysis in the networks will be more telling on communities of ‘team SA’. In the future, Artificial Intelligence or Big Data analytics embedded in the ICT infrastructure may provide *autonomous* software agents that interact with other *automated* as well as human components and of themselves add-value in terms of SA based on their inputs. SAWN may straightforwardly provide a tool for mapping the technological component links as well as the human and a means of analysing the value of a chain of human operators against a technological agent.

A challenge for the future is to streamline the questionnaire administration. In the Baseline case with Excel spreadsheets, respondents found the survey challenging and frustrating because of subtle differences between statements reflecting incremental progression through Endsley's SA model and navigating long lists of products and organisations. This was despite break up of forms into logically discrete parts and digital ‘smarts’ providing explanations. These challenges were overcome in the interview, with the interviewer explaining subtleties and guiding the eye of the interviewee across colour coded lists. However, for more senior officers this led to long interviews, up to 90 min in some cases. Though less than the 2 h cited for CDM, it was still a challenge for operational staff. Of course, in light of the aforementioned incorporation of data analytics in enterprise ICT systems, SAWN data collection may be automated and conducted in real-time using text-analysis algorithms able to classify the SA level of a human output, or software agents able to classify their own outputs and inputs using a scheme such as that presented here.

SAWN may be extended across the entire spectrum of OODA ‘levels’ to Decision and Performance of Actions. Such a representation would then be applicable across all aspects of C2, emergency management and operations control organisations. However, given the 13 gradations of SAWN, a simplification is required to bring the extended model back into a range manageably for survey respondents. We recently trialled an eight level OODA model elsewhere (Kalloniatis et al., 2016) and obtained reasonable useability and fidelity. In the present paper, we applied the model to an organisation in real operational circumstances for steady-state and a hypothetical crisis scenario. In neither case did we have access to ‘ground truth’ to ‘validate’ the situation awareness of participants - just as in SART. But SAWN, by integrating different perspectives on the same information product, allows for triangulation of the subjective judgements of operators. SAWN is also applicable to simulated environments such as human-in-the-loop experiments or command post exercises where ‘ground truth’ may be available allowing for more thorough validation of reported operator awareness. In keeping with the EAST and WESTT (Houghton et al., 2008) methodologies, SAWN can be also applied post-event and to non-military environments, such as emergency management, air traffic controllers and plant room operators, which frequently step between steady-state and crisis events; these provide further suitable contexts for method validation.

[7] The three paths with highest SA gradient and the three with lowest.

Appendix 1. SAWN data gathering instrument

SAWN Survey Questionnaire

SA Level	Statements pertaining to Products	Statements pertaining to Interactions
Perception	*P1a* I used the following products to draw my attention to an asset of interest	*O1a* I interacted with the following organisations to draw my attention to an asset of interest
	P1b I prepared the following products to draw the attention of others to an asset of interest	*O1b* I interacted with the following organisations to draw the attention of others to an asset of interest
	P2a I am using the following products to identify the character, type, location and capabilities of the asset(s) of interest	*O2a* I am interacting with the following organisations to identify the character, type, location and capabilities of the asset(s) of interest
	P2b I am preparing the following products to enable others to identify the character, type, location and capabilities of the asset(s) of interest	*O2b* I am interacting with the following organisations to enable others to identify the character, type, location and capabilities of the asset(s) of interest
	P3a I am using the following products as a sufficient source to authenticate the character, type, location and capabilities of the asset(s) of interest	*O3a* I am interacting with the following organisations as a sufficient source to authenticate the character, type, location and capabilities of the asset(s) of interest
	P3b I am preparing the following products as a sufficient source for others to authenticate the character, type, location and capabilities of the asset(s) of interest	*O3b* I am interacting with the following organisations as a sufficient source for them to authenticate the character, type, location and capabilities of the asset(s) of interest
Comprehension	*P4a* I am using the following products to understand the relationship (order of battle, organisational structure) of the asset(s) of interest to other assets in a given area	*O4a* I am interacting with the following organisations to allow me to understand the relationship (order of battle, organisational structure) of the asset(s) of interest to other assets in a given area
	P4b I am preparing the following products to aid others' understanding of the relationship (order of battle, organisational structure) of the asset(s) of interest to other assets in a given area	*O4b* I am interacting with the following organisations to aid others' understanding of the relationship (order of battle, organisational structure) of the asset(s) of interest to other assets in a given area
	P5a I am using the following products to determine the current actions of the asset(s) in a given area	*O5a* I am interacting with the following organisations to determine the current actions of the asset(s) in a given area
	P5b I am preparing the following products to help others to determine the current actions of the asset(s) in a given area	*O5b* I am interacting with the following organisations to help others to determine the current actions of the asset(s) in a given area
	P6a Based on the combination of the following products about the past history of the asset(s) of interest, I am able to understand the immediate implications of the actions of this asset in a given area	*O6a* Based on the past history of the asset(s) of interest, I am interacting with the following organisations to understand the immediate implications of the actions of this asset in a given area
	P6b Based on my knowledge of the past history of the asset(s) of interest, I am preparing the following products to aid others' understanding of the immediate implications of the actions of this asset in a given area	*O6b* Based on my knowledge of the past history of the asset(s) of interest, I am interacting with the following organisations to aid their understanding of the immediate implications of the actions of this asset in a given area
	P7a I am using the following products to understand the immediate level of risk the asset(s) of interest presents to Australian assets	*O7a* I am interacting with the following organisations to understand the immediate level of risk the asset(s) of interest presents to Australian assets
	P7b I am preparing the following products to aid others' understanding of the immediate level of risk the asset(s) of interest presents to Australian assets	*O7b* I am interacting with the following organisations to aid others' understanding of the immediate level of risk the asset(s) of interest presents to Australian assets
	P8a I am using the following products to understand possible consequences of the presence of the asset(s) of interest in a given area on the overall strategic picture	*O8a* I am interacting with the following organisations to understand possible consequences of the presence of the asset(s) of interest in a given area on the overall strategic picture
	P8b I am preparing the following products to aid others' understanding of possible consequences of the presence of the asset(s) of interest in a given area on the overall strategic picture	*O8b* I am interacting with the following organisations to aid others' understanding of possible consequences of the presence of the asset(s) of interest in a given area on the overall strategic picture
Projection	*P9a* I am using the following products to anticipate possible actions of the asset(s) of interest in a given area during the next 36 h	*O9a* I am interacting with the following organisations to help me anticipate possible actions of the asset(s) of interest in a given area during the next 36 h
	P9b I am preparing the following products to help others anticipate possible actions of the asset(s) of interest in a given area during the next 36 h	*O9b* I am interacting with the following organisations to help others anticipate possible actions of the asset(s) of interest in a given area during the next 36 h
	P10a I am using the following products to anticipate possible actions of the asset(s) of interest in a given area beyond the next 36 h	*O10a* I am interacting with the following organisations to help me anticipate possible actions of the asset(s) of interest in a given area beyond the next 36 h
	P10b I am preparing the following products to help others anticipate possible actions of the asset(s) of interest in a given area beyond the next 36 h	*O10b* I am interacting with the following organisations to help others anticipate possible actions of the asset(s) of interest in a given area beyond the next 36 h
	P11a I am using the following products to anticipate the effect of physical environmental conditions in a given area during the next 36 h on the behaviour of asset(s) of interest	*O11a* I am interacting with the following organisations to help me anticipate the effect of physical environmental conditions in a given area during the next 36 h on the behaviour of asset(s) of interest
	P11b I am preparing the following products to help others anticipate the effect of physical environmental conditions in a given area during the next 36 h on the behaviour of asset(s) of interest	*O11b* I am interacting with the following organisations to help others anticipate the effect of physical environmental conditions in a given area during the next 36 h on the behaviour of asset(s) of interest
	P12a I am using the following products to decide that the asset(s) in a given area is no longer of consequence	*O12a* I am interacting with the following organisations to help me decide that the asset(s) in a given area is no longer of consequence
	P12b I am preparing the following products to help others decide that the asset(s) in a given area is no longer of consequence	*O12b* I am interacting with the following organisations to help others decide that the asset(s) in a given area is no longer of consequence

Appendix 2. Expanded SAWN diagrams

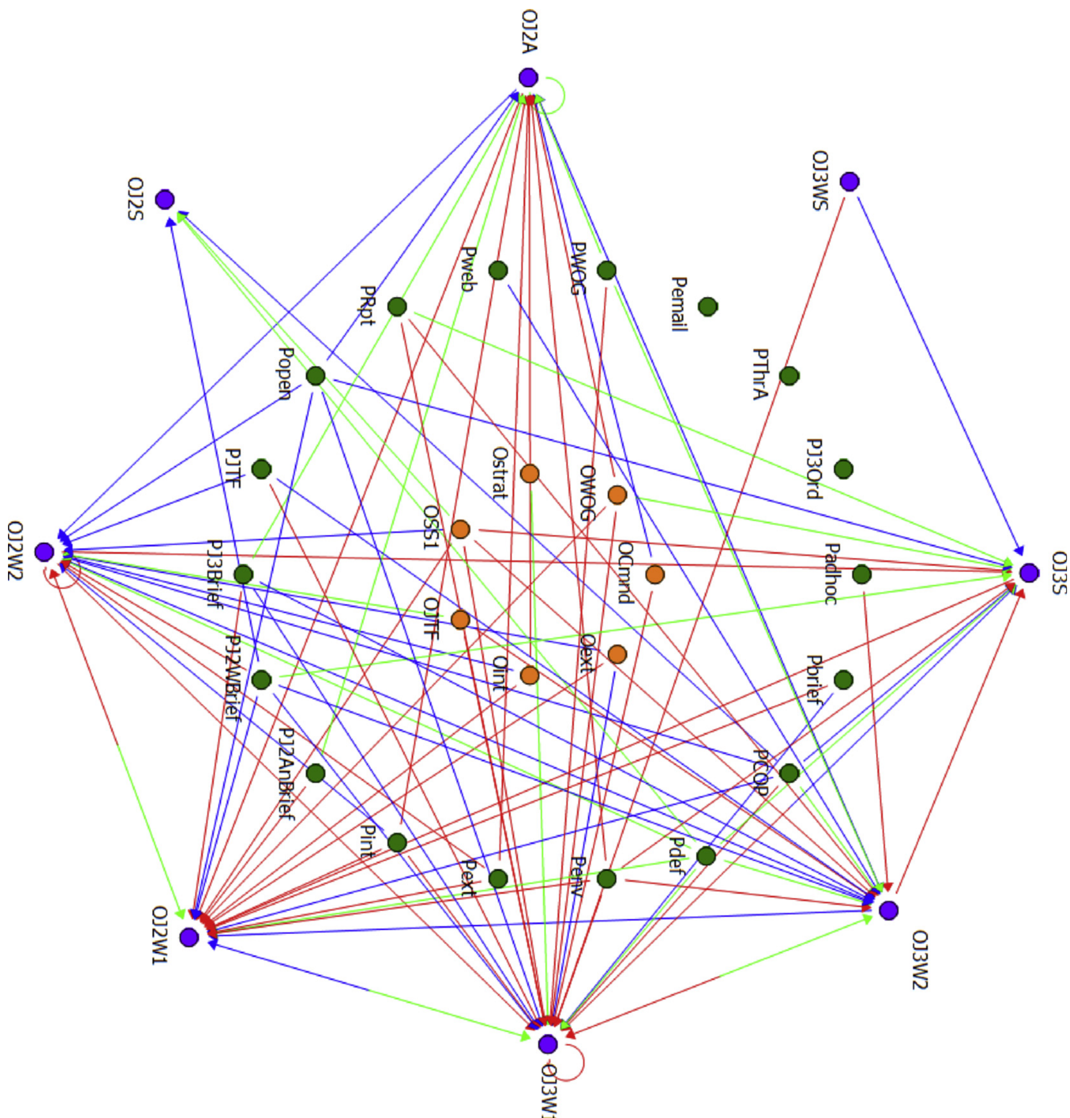

Fig. 11. SAWN Baseline pull.

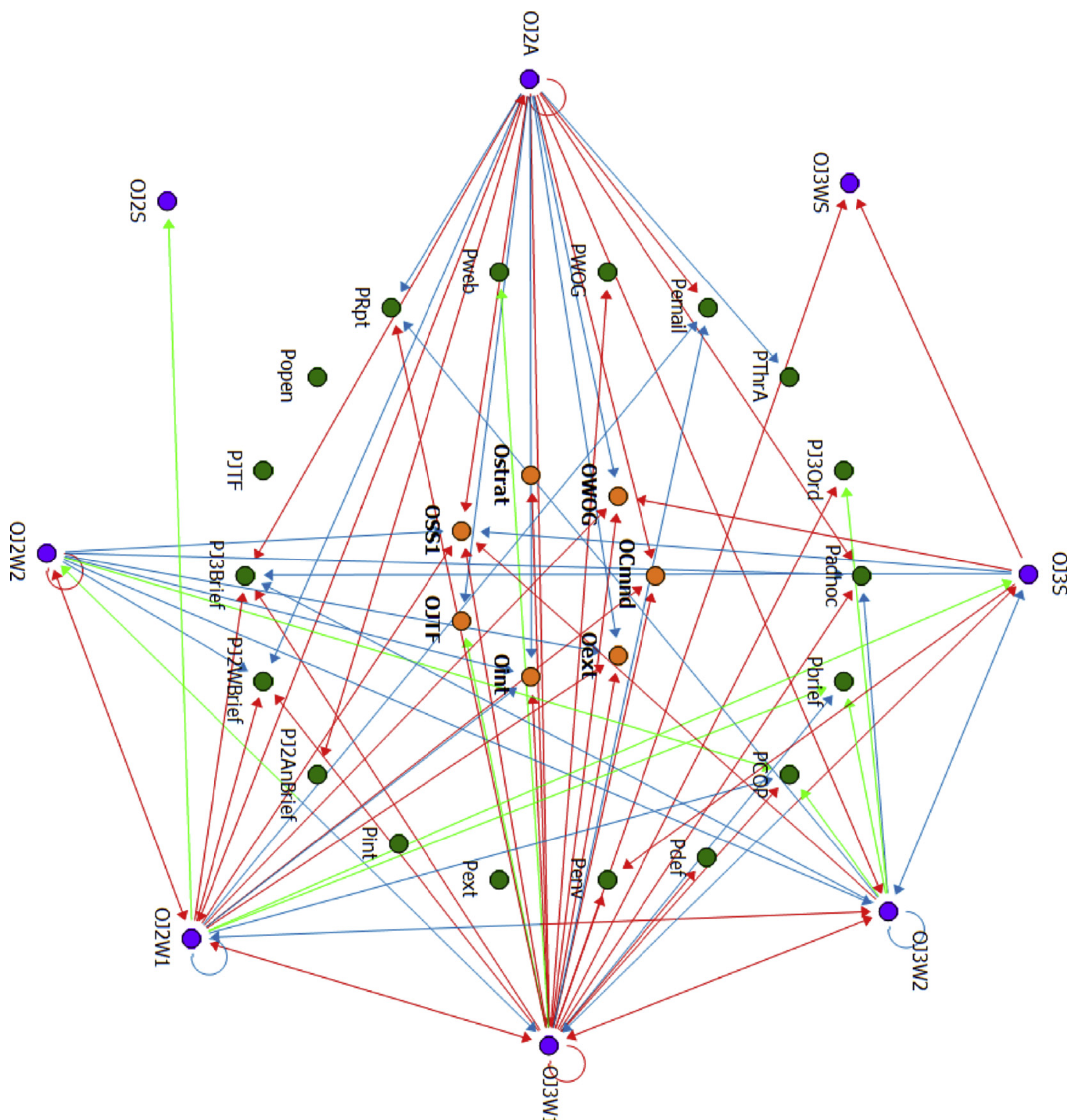

Fig. 12. SAWN Baseline push.

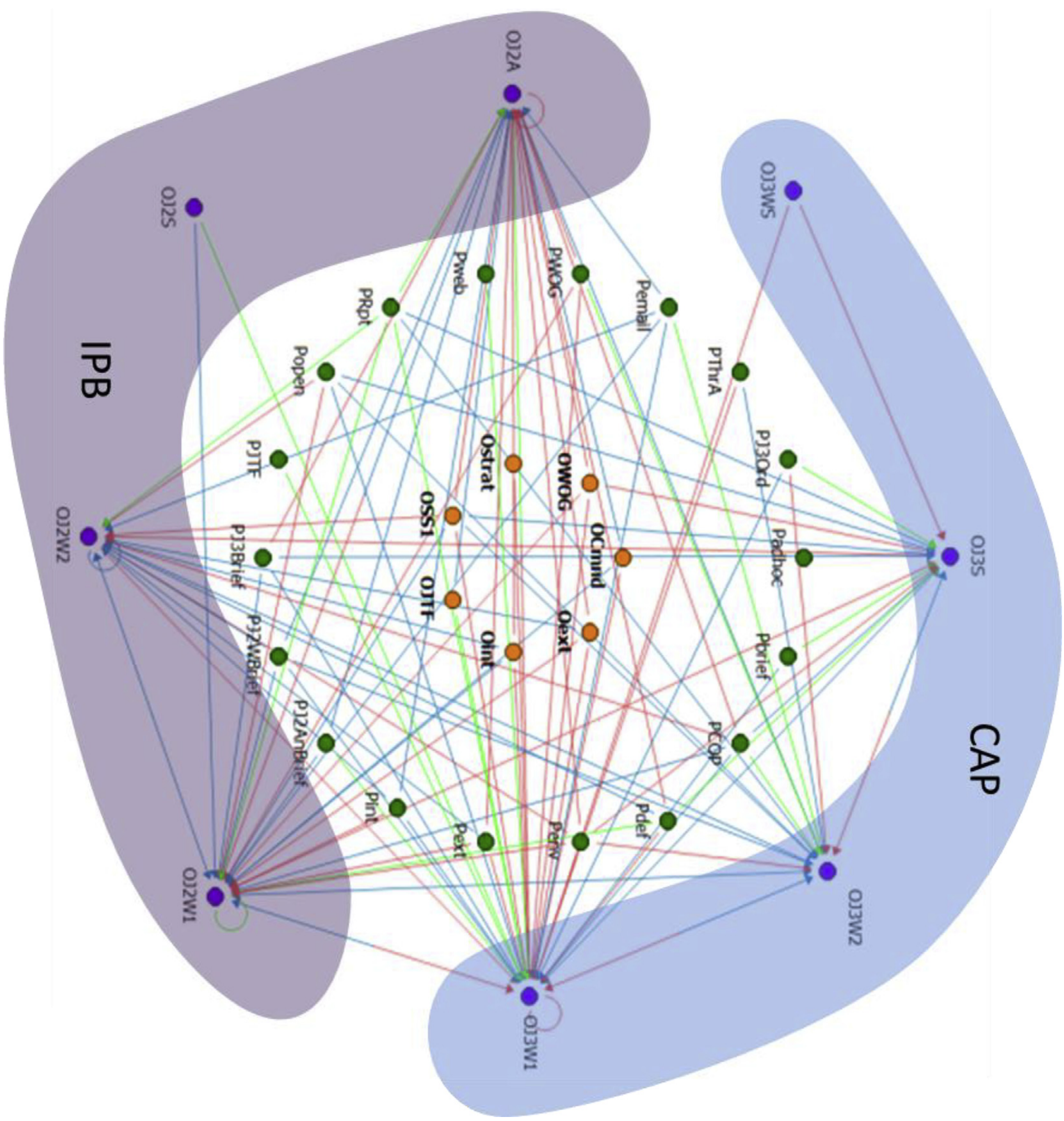

Fig. 13. SAWN Scenario pull.

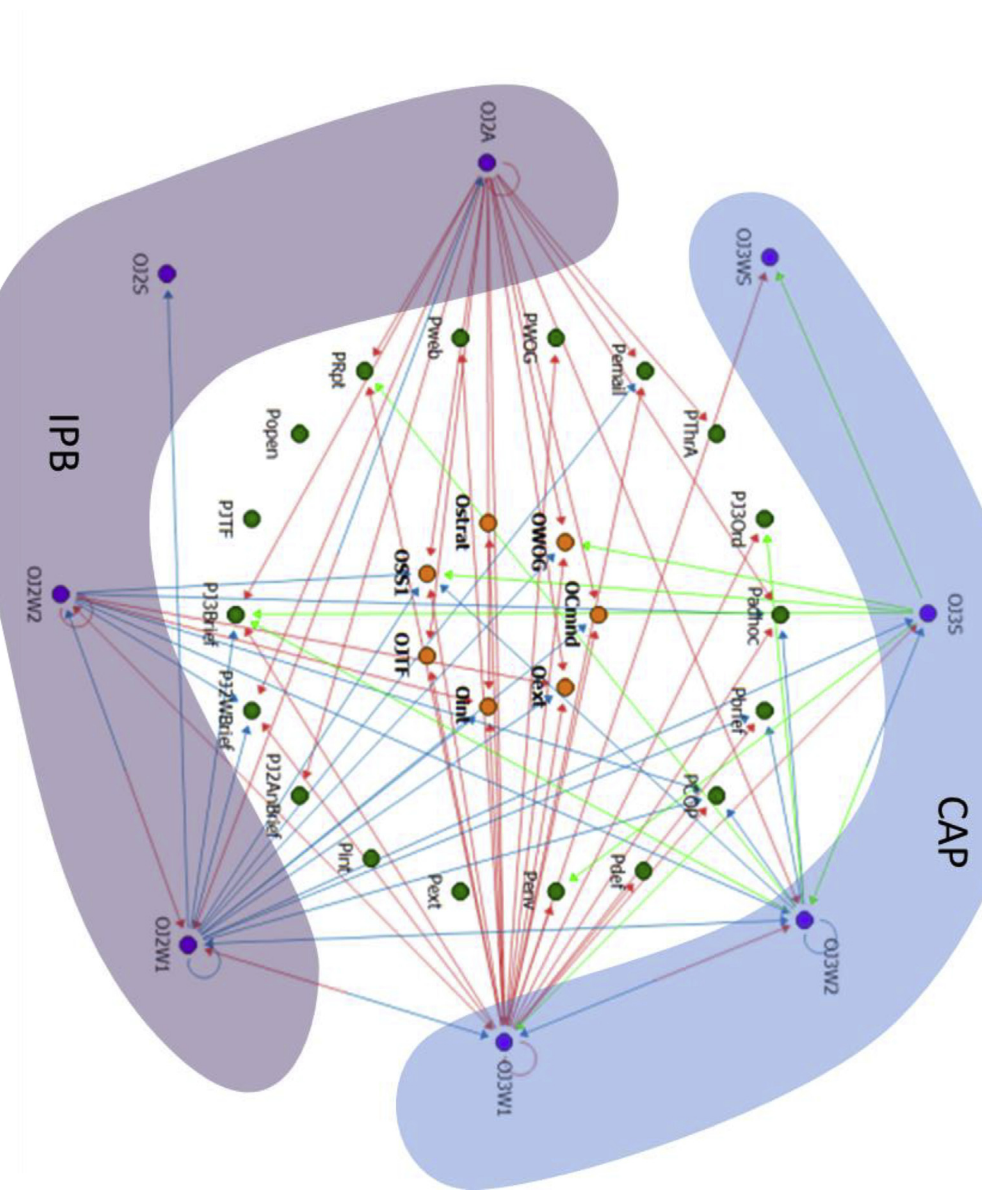

Fig. 14. SAWN Scenario push.

References

Adams, M.J., Tenney, Y.J., Pew, R.W., 1995. Situation awareness and the cognitive management of complex systems. Hum. Factors 37, 85–104.

Afifi, W.A., Weiner, L., 2002. Information seeking across contexts. Hum. Commun. Res. 28 (2), 207–212.

Alberts, D.S., Gartska, J.J., Stein, F.P. 1999. "Network Centric Warfare: Developing and Leveraging Information Superiority", Command and Control Research Program (CCRP) Publication Series.

Ali, I., Kalloniatis, A., Kohn, E., La, P., Macleod, I., Neville, T., Zuparic, M. 2014. "The Situation Awareness Network (SAWN) Model", 19th International Command and Control Research and Technology Symposium (ICCRTS), June 16–19, Alexandria, VA, USA.

Anderson, J., 1983. The Architecture of Cognition. Harvard University Press, Cambridge, MA.

Artman, H., 1999. Situation Awareness and cooperation within and between hierarchical units in dynamic decision-making. Ergonomics 42, 1404–1417.

Banburry, S.P., Croft, D.G., MacKen, W.J., Jones, D.M., 2004. A cognitive streaming account of situation awareness. In: Banburry, S., Tremblay, S. (Eds.), A Cognitive Approach to Situation Awareness: Theory and Application. Ashgate, Aldershot, pp. 117–137.

Barabasi, A.-L., Albert, R., 2002. Statistical mechanics of complex networks. Rev. Mod. Phys. 74, 47–97.

Berger, C.R., Calabrese, R.J., 1975. Some exploration in initial interaction and beyond: toward a developmental theory of communication. Hum. Commun. Res. 1, 99–112.

Bourbousson, J., R'Kiouak, M., Eccles, D.W., 2015. The dynamics of team coordination: a social network analysis as a window to shared awareness. Eur. J. Work Organ. Psychol. 24, 742–760.

Boyd, J., 1987. A Discourse on Winning and Losing. M. A. F. Base. Air University Library. Doc. No. M-U 43947.

Burke, C.S., Stagl, K.C., Salas, E., Pierce, L., Kendall, D., 2006. Understanding team adaptation: a conceptual analysis and model. J. Appl. Psychol. 91 (6), 1189–1207.

Chiappe, D., Rorie, R.C., Morgan, C.A., Vu, K., 2014. A situated approach to the acquisition of shared SA in team contexts. Theor. Issues Ergon Sci. 15 (1), 69–87.

Chung, F.R.K., 1997. Spectral Graph Theory: Regional Conference Series in Mathematics Number 92. American Mathematical Society, Providence RI.

Clegg, C.W., 2000. Sociotechnical principles for system design. Appl. Ergon. 31, 463–477.

Cognitive Edge, 2013. The Origins of Cynefin. http://cognitive-edge.com (Accessed July 2013).

Crandall, B., Klein, G., Hoffman, R., 2006. Working Minds: A Practitioner's Guide to Cognitive Task Analysis. MIT Press, Cambridge, MA.

Czégel, D., Palla, G., 2015. Random walk hierarchy measure: what is more hierarchical, a chain, a tree or a star? Sci. Rep. 5 (17994) http://dx.doi.org/10.1038/srep17994.

de Alwis, G., Majid, S., Chaudhry, A.S., 2006. Transformation in managers' information seeking behaviour: a review of the literature. J. Inf. Sci. 32 (4), 362–377.

Dumbill, E., 2012. Planning for Big Data: a CIO's Handbook to the Changing Data Landscape. O'Reilly Media, Sebastopol, California.

Durso, F.T., Hackworth, C.A., Truitt, T.R., Crutchfield, J., Nikolic, D., Manning, C.A., 1999. Situation Awareness as a Predictor of Performance in En Route Air Traffic Controllers. Technical Report. DOT/FAA/AM-99/3, January.

Endsley, M.R., 1987. SAGAT: a Methodology for Measuring Situation Awareness. (NOR DOC 87–83). Northrop Corporation, Hawthorne, CA.

Endsley, M.R., 1988. Design and evaluation of situation awareness enhancement. In: Proceedings of the Human Factors Society 32nd Annual Meeting. CA. Human Factors Society, Santa Monica, pp. 97–101.

Endsley, M.R., 1990. A methodology for the objective measurement of pilot situation awareness. AGARDCP-478. In: Situational Awareness in Aerospace Operations. NATO-AGARD, Neuilly Sur Seine, France, pp. 1/1–1/9.

Endsley, M.R., 1995. Toward a theory of situation awareness in dynamic systems. Hum. Factors 37 (1), 32–64.

Endsley, M.R., 2000. Theoretical underpinnings of situation awareness: a critical review. In: Endsley, M.R., Gerland, D.J. (Eds.), Situation Awareness Analysis and Measurement. Lawrence Erlbaum Associates, New York, pp. 1–24.

Endsley, M.R., 2015. Situation awareness misconceptions and misunderstandings. JCEDM 9 (1), 4–32.

Endsley, M.R., Jones, W.M., 1997. Situation Awareness Information Dominance and Information Warfare. AL/CF-TR-1997-0156. United States Air Force report.

Fiore, F.M., Salas, E., 2004. Why we need team cognition. In: Salas, E., Fiore, S.M. (Eds.), Team Cognition: Understanding the Factors that Drive Process and Performance. American Psychological Association, Sheridan Books, Ann Arbor, Mich, pp. 235–248.

FM 3-0, 2008. "Operations", Field Manual No. 3-0. Department of the Army, Washington DC, 27 February.

FM 34-130, 1994. "Intelligence Preparation of the Battlefield." Field Manual 34-130. Headquarters Department of the Army, Washington DC, 8 July.

Fowlkes, J.E., Salas, E., Baker, D.P., Cannon-Bowers, J.A., Stout, R.J., 2000. The utility of event-based knowledge elicitation. Hum. Factors 42, 24–35.

Friedkin, N.E., 1991. Theoretical foundations of centrality measures. Am. J. Sociol. 96, 1478–1504.

Gorman, J.C., Cooke, N.J., Winner, J.L., 2006. Measuring team situation awareness in decentralized command and control environments. Ergonomics 49, 12–13.

Hew, P., 2011. Reconciling situation awareness in humans versus machines via mode awareness and schemata. Theor. Issues Ergon Sci. (Oct) 1–22. http://dx.doi.org/10.1080/1463922.614701.

Hoffman, R.R., Crandall, B., Shadbolt, N., 1998. Use of the critical decision method to elicit expert knowledge: a case study in the methodology of cognitive task analysis. Hum. Factors 40 (2), 254–276.

Houghton, R.J., Baber, C., Cowton, M., Walker, G.H., Stanton, N.A., 2008. WESTT (workload, error, situational awareness, time and teamwork): an analytical prototyping system for command and control. Cogn. Technol. Work (10), 199–207.

Hutchins, E., 1995. Cognition in the Wild. MIT Press, Cambridge MA.

Jenkins, D.P., Walker, G.H., Stanton, N.A., Salmon, P.M., 2012. Distributed Situation Awareness: Theory, Measurement and Application to Teamwork (Human Factors in Defence). Ashgate.

JFSC, 2000. The Joint Staff Officer's Guide 2000. JFSC Pub 1. Joint Forces Staff College, USA.

JP, 2011. Joint Operational Planning. Joint Publication 5-0. US Department of Defence, Chairman of the Joint Chiefs of Staff, 11 August.

Kalloniatis, A., Rowe, C., La, P., Holder, A., Bennier, J., Mitchell, B.2016. Network analysis of decision loops in operational Command and Control arrangements, Defence Operations Research Symposium (DORS), Canberra, 15–18 November 2016.

Klein, G.A., 2015. Whose fallacies? JCEDM 9 (1), 55–58.

Klein, G.A., Calderwood, R., MacGregor, D., 1989. Critical decision method for eliciting knowledge. IEEE Trans. Syst. Man Cybern. 19 (3), 462–472.

NATO, 2006. Exploring New Command and Control Concepts and Capabilities. Final Report of the NATO SAS-050. http://www.rta.nato.int/activity_pfp.asp?ACT=SAS-050.

Neisser, U., 1976. Cognition and Reality: Principles and Implications of Cognitive Psychology. Freeman, San Francisco.

Neville, T.J., 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 59 (7), 962–975. http://dx.doi.org/10.1080/00140139.2015.1100758.

Neville, T.J., Salmon, P.M., Read, G.J.M., Kalloniatis, A.C., 2016. Play on or call a foul: testing and extending distributed situation awareness theory through sports officiating. Theor. Issues Ergon Sci. 17 (1), 80–103. http://dx.doi.org/10.1080/1463922x.2015.1106617.

Osinga, F., 2013. 'Getting' a discourse on winning and losing: a primer on Boyd's 'theory of intellectual evolution'. Contemp. Secur. Policy 34 (3), 603–624.

Pigeau, R., McCann, C., 2000. Redefining command and control. In: McCann, C., Pigeau, R. (Eds.), The Human in Command: Exploring the Modern Military Experience. Kluwer Academic, London, pp. 163–184.

Plant, K.L., Stanton, N.A., 2016. Distributed Cognition in Search and Rescue: loosely coupled tasks and tightly coupled roles. Ergonomics 1–21.

Rentsch, J.R., Klimoski, J.R., 2001. Why do 'great minds' think alike? Antecedents of team member schema agreement. J. Organ. Behav. 22, 107–120.

Ropohl, G., 1982. Some methodological aspects of modelling socio-technical systems. In: Trappl et al., R. (Ed.), Progress in Cybernetics and Systems Research,, vol. 10. Hemisphere, Washington, DC, pp. 525–536.

Salas, E., Prince, C., Baker, P.D., Shrestha, L., 1995. Situation awareness in team performance. Hum. Factors 37 (1), 123–126.

Salmon, P.M., Stanton, N.A., Walker, G.H., Jenkins, D.P., Ladva, D., Rafferty, L., Young, M., 2009. Measuring situation awareness in complex systems: comparison of measure study. Int. J. Industrial Ergon 39, 490–500.

Salmon, P.M., Stanton, N.A., Walker, G.H., Jenkins, D.P., Rafferty, L., 2010. Is it really better to share? Distributed situational awareness and its implications for collaborative design. Theor. Issues Ergon Sci. 11 (1–2), 58–83.

Saner, L.D., Bolstad, C.A., Gonzalez, C., Cuevas, H.M., 2009. Measuring and predicting shared situation awareness in teams. J. Cogn. Eng. Decis. Mak. Fall 280–308.

Shu, Y., Furuta, K., 2005. An inference method of team situation awareness based on mutual awareness. Cogn. Technol. Work 7, 272–287.

Smith, K., Hancock, P.A., 1994. Situation Awareness is adaptive, externally-directed consciousness. In: Gilson, R.D., Garland, D.J., Koonce, J.M. (Eds.), Situational Awareness in Complex Systems. Embry-Riddle Aeronautical University Press, Daytona beach, Florida, pp. 59–68.

Stachowski, A.A., Kaplan, S.A., Walker, M.J., 2009. The benefits of flexible team interaction during crises. J. Appl. Psychol. 94 (6), 1536–1543.

Stanton, N.A., Stewart, R., Harris, D., Houghton, R.J., Baber, C., McMaster, R., Salmon, P.M., Hoyle, G., Walker, G.H., Young, M.S., Linsell, M., Dymott, R., Green, D.A., 2006. Distributed situation awareness in dynamic systems: theoretical development and application of an ergonomics methodology. Ergonomics 45, 1288–1311.

Stanton, N.A., Salmon, P.M., Walker, G.H., Jenkins, D., 2009. Genotype and phenotype schemata and their role in distributed situation awareness in collaborative systems. Theor. Issues Ergon Sci. 10 (1), 43–68.

Stanton, N.A., Salmon, P.M., Walker, G.H., 2015. Let the reader decide: a paradigm shift for situation awareness in sociotechnical systems. JCEDM 9 (1), 44–50.

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

Walker, G.H., Gibson, H., Stanton, N.A., Baber, C., Salmon, P., Green, D., 2006. Event analysis of systemic teamwork (EAST): a novel integration of ergonomics methods to analyse C4i activity. Ergonomics 49 (12–13), 1345–1369.

Walker, G.H., Stanton, N.A., Baber, C., Wells, L., Gibson, H., Salmon, P., Jenkins, D., 2010. From ethnography to the EAST method: a tractable approach for representing distributed cognition in air traffic control. Ergonomics 53 (2), 184–197.
Wartofsky, M.W., 1979. Models: Representation and the Scientific Understanding, Boston Studies in the Philosophy of Science, Vol. XLVIII. D. Reidel Publishing, Dordrecht, Boston, London.
Wasserman, S., Faust, K., 1994. Social Network Analysis: Methods and Applications. Cambridge University Press, U.K.
Watts, D.J., Strogatz, S., 1998. Collective dynamics of 'small-world' networks. Nature 393 (6684), 440–442.
Williams, D.K., 2013. What a Fighter Pilot Knows about Business. Forbes. February 19.