15th ICCRTS
“The Evolution of C2”

Comparison of Situational Awareness in Hierarchical C2 and Edge Network Structures

Paper ID: 038

Topics: 2, 3, and 5.

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Abstract

The phenomenon of situational awareness (SA) has received considerable attention in recent years and significant theoretical advances have been made which establish that SA is an important component of teamwork. This is especially true in complex environments, such as in command and control, where the team is required to deal with decision-making problems under significant pressure. Two models of Team SA have generated interest, firstly, a model of Shared SA which describes Team SA as the level of overlap in common SA elements between team members (Endsley, 1995). In contrast, the recent model of Distributed SA considers team members to have compatible, but not identical SA (Stanton et al., 2006). Using ELICIT, an intelligence gathering game, an experiment was conducted which compares the manifestation of team SA in a Hierarchical network structure with that of an Edge network structure. In addition this study considered the type of SA prevalent in the two network structures and measured both Shared and Distributed SA. Understanding the type of SA prevalent in diverse network structures is important when considering future developments of C2.

1. Introduction

This work is derived from the question; ‘what is the best command and control structure to adopt for what sort of situations’. In our opinion Situation Awareness (SA) is vital to agility in network structures and its nature and operation in different network structures merits investigating.

Stanton, Salmon, Walker and Jenkins (2010) describe three schools of thought regarding the phenomenon of SA, two of which we utilise here; the psychological and the systems ergonomics school. In the first school of thought SA is seen as a psychological phenomenon residing entirely within the mind of an individual person, whereas the systems ergonomics approach considers SA as an emergent property which arises from an agent's interaction with the world (Stanton, Stewart, Harris, Houghton, Baber, McMaster, Salmon, Hoyle, Walker, Young, Linsell, Dymott and Green, 2006). This school see SA as a phenomenon of distributed cognition; hence the systems ergonomics approach sees the mind as situated within an interdependent relationship with the world (Stanton et al., 2010). These approaches are considered in greater depth in the following sections.

1.1. Psychological approach

The psychological school of thought considers SA as an individual characteristic, something which is produced and contained within the mind of an operator (Stanton et al., 2010). Of the contributions within this school of thought Endlsey's (1995) three-level model has received most attention. Endsley (1995) define SA as:

> "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future (p. 5)".

SA is perceived to consist of three separate levels, *perception*, *comprehension*, and *projection* (Endsley, 1995). By piecing together the data in the environment (perception) and understanding it (comprehension) the individual can make assumptions about the future (projection) and act accordingly.

Endsley's (1995) definition is often favoured in the literature due to its simplicity and ease of assessing SA. There are, however, some criticisms of the model. For instance, it does not explain situations in which SA is a continuous process, nor does it scale up to explain team SA comprehensively. According to the psychological approach to SA team SA can be understood as shared SA where individual team members share the same SA requirements. It has been argued by a number of authors (e.g. Salas, Prince, Baker and Schrestja, 1995; Masys, 2005; Salmon et al., 2008; Stanton, Salmon, Walker and Jenkins, 2009) that team SA is more than the sum of its parts. As such it is not adequate to merely add individual team members' SA together to provide a representation of team SA.

The psychological notion of team SA emphasise the psychological qualities of the individual as imperative to achieve SA, relying on cognitive capabilities. For instance, Sarter and Woods (1991) consider SA as a variety of cognitive processing activities that are critical to dynamic performance. The individual develops a mental theory of the world that aids comprehension of how elements fit together and how future states of the world can be predicted (Banbury, Croft, Macken and Jones, 2004). Bedny and Meister (1999) argue that SA phenomena can only be understood as part of cognitive activity that is intensely dynamic. Similarly Artman (2000) refer to SA as *'active construction of a situation model'*. This emphasises the individual as being an active mediator in developing and maintaining SA. As the above indicates the psychological school of thought takes the position that several cognitive processes underlie the development of SA, and indeed the ability to maintain SA is challenged by the limitations in cognitive processing (Endsley, 1999). Attention and memory, schemata, mental models, goal-driven processing and experience are the most important of these. Their role in achieving SA and their limitations have been addressed in detail elsewhere (e.g. Endsley, 1995; 1999; 2000; Banks and Millward, in press).

1.2. Systems approach

The systems ergonomics school is influenced by distributed cognition (Hutchins, 1995a, b) and sociotechnical theory (Walker et al., 2009); and takes a systems approach to the study of SA. Stanton et al. (2006) proposed a theory of distributed

SA which consists of four theoretical concepts: schema theory, genotype and phenotype schema, perceptual cycle model of cognition, and the distributed cognition approach. This model considers SA as an emergent property of collaborative systems (Salmon, Stanton, Walker, Baber, Jenkins, McMaster and Young, 2008; Salmon et al., 2009). According to Salmon et al. (2008) distributed SA is based on:

> 'the notion that in order to understand behaviour in complex systems it is more useful to study the interactions between parts in the system and the resultant emerging behaviour rather than the parts themselves' (p.369)'.

They argue that people and artefacts comprising a system together form a "joint cognitive system" (Hollnagel, 2001) and that cognitive processes emerge from and are distributed across this system (Salmon et al., 2008). Distributed cognition is a function of interaction between human and technological agents involved in collaborative activity (Salmon et al., 2008; 2009).

Smith and Hancock (1995) draw on Neisser's (1976) model in explaining SA. They argue that information and action flow continuously around the cycle and;

> 'the environment informs the agent, modifying its knowledge. Knowledge directs the agent's activity in the environment. That activity samples and perhaps anticipates or alters the environment, which in turn informs the agent (p.141)".

The distributed SA model does not discount the importance of the individual to SA, but rather argue that the individual is only one part of the system (Stanton et al, 2006) They argue that an individual possesses genotype schemata that are activated by the task relevant nature of task performance (Salmon et al., 2009). During task performance the phenotype schema is brought to the fore in the ensuing interaction between the people, the world and artefacts (Salmon et al., 2009). The individual then is closely coupled to its environment and can therefore not be meaningfully analysed as separate from it (Bedny and Meister, 1999).

Rather than SA being shared among team members Stanton et al. (2006) considers team members to possess unique but compatible parts of overall system awareness. It is compatible awareness that holds distributed systems together (Stanton et al., 2006; 2009; Salmon et al., 2009). SA transactions allow agents within collaborative systems to enhance each other's awareness, such as exchange of SA relevant information (Salmon et al., 2009). The information is being used for each agents own ends, integrated into their own schemata, and interpreted individually in light of their own tasks and goals (Salmon et al., 2008; 2009). SA in distributed teams is therefore enhanced through transactions, rather than being shared, and transactions update each agents SA (Salmon et al., 2009). Distributed SA is defined by Stanton et al. (2006) as:

> 'activated knowledge for a specific task, at a specific time within
> a system' (p. 1291).

This means that information held by the system becomes active at different points in time based on the goals and activities being performed and their requirements (Salmon et al., 2008). Each individual holds different SA for the same situation, depending on his or her activities and goals (Salmon et al., 2008). The connections between the different parts of the model are maintained where necessary, e.g. by communication and interaction. Communication can function as one form of SA transaction. The distributed SA model therefore provides the means to view:

> ‘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’ (Stanton et al., 2010, p.5).

As the above indicates a lot remains in terms of determining the type of SA which best explains the prevalence of it in teams. We report on a study which is part of on-going work to identify the role of SA in different network structures performance and ultimately their agility. We have taken an initial step to illuminate this issue by comparing SA in hierarchical and Edge structures and by using the psychological and systems ergonomics perspectives to analyse the SA found.

2. Method

2.1. Participants

A sample of 34 where drawn from the University of Southampton postgraduate population. These were randomly divided in two groups, one Hierarchical and one Edge network condition. In the Hierarchical condition there were 17 participants with a mean age of 28.18, 15 of which were male and 2 were female. The Edge condition similarly had 17 participants, mean age of 28.67, 12 males and 5 females.

2.2. Design

This study used an ELICIT baseline approach which is of a mixed experimental design. The between variable is organisation type; hierarchical and edge, while the within subject variable is trial iteration with four factoid sets. Participants are randomly assigned to two groups: edge or the hierarchical group. The aim of each game is for the group to utilise the network structure they have been organised in to correctly identify who, what, where and when of the adversary attack. This is done by combining information, posting it on relevant group web pages and sharing it with relevant people (Ruddy, 2007). A full explanation of the ELICIT baseline experiment design and procedure can be found elsewhere (for instance Ruddy, 2007).

The independent variable for this study was organisation type; Hierarchical and Edge, while situation awareness is the dependent variable. We expected both conditions to have obtained some SA, however, given the notion of Shared SA as described above as shared SA requirements we expect the Edge condition to have a higher SAGAT score than that of the Hierarchical condition as the team members in Edge are expected to perform the same task. Further, we expected the Hierarchical condition to spend less time to complete the task.

2.3. Analysis

To compare difference in mean rank of SAGAT and SART scores between the two groups the non-parametric A Mann-Whitney test was performed. Equally a t-test was conducted to analyse difference in means between the two groups for SAGAT and SART.

The ELICIT Log Analyser (CCRP, 2009) was used to extract data from the ELICIT software. Measures of correct identify, duration of game and sharing behaviours as indicated by share, post and pull were collected from the ELICIT software. In addition a Situation Awareness Global Assessment Technique (SAGAT) questionnaire was administered and a SAGAT score calculated (Endsley, 2000). The SAGAT score, combined with an inspection of individual responses' overlap on specific queries, give an indication of Shared SA in the two conditions. SAGAT the most widely used of SA measures and is considered an objective measure of individuals SA (Endsley et al., 1998). The objectivity is ensured by the freeze-probe technique which involves the simulation of any normal operation is frozen at random points in time and queries about the situation are asked (Endsley et al., 1998). The participants are required to answer each query based on the knowledge of the situation at the point of the freeze (Salmon et al., 2006). See Table 1 for a sample of SAGAT queries given.

Table 1: Example SAGAT queries and corresponding SA levels.

Q1	When is the terrorist incident going to happen?	Level 1
Q2	What target is likely to be attacked?	Level 2
Q3	When are they going to strike?	Level 1
Q4	Based on the information you were given throughout the mission what did you think the terrorist group would do?	Level 3

A SAGAT score is calculated for each participant after the simulation. The operator's perceptions are compared to the actual state of the environment to provide an objective measure of the operators SA (Endsley and Rodgers, 1996). Although heavily criticised when used to provide a team SA score the SAGAT scores of the individual in the team is averaged to provide an overall team SA score (Salas, Prince, Baker and Schrestja, 1995; Masys, 2005; Salmon et al., 2008; Stanton, Salmon, Walker and Jenkins, 2009).

A Situation Awareness Rating Technique (SART) questionnaire was also used (Taylor, 1990). SART is also a popular measure of SA and provides an assessment of SA based on an operators' subjective opinion (Endsley et al. 1998). It consists of 14 components which are determined in relation to their relevance to the task or environment under study (Endsley et al. 1998). The operators are required to rate on a series of bipolar scales the degree to which they perceive a) a demand on their resources, b) a supply of resources available to them, and c) their understanding of the situation (Endsley et al., 1998). The scales are combined to provide an overall measure of SA (Endsley et al., 1998). The popularity of particularly SAGAT, but also

SART, can not be ignored when studying SA and as such their fitness for purpose in relation to ELICIT studies was sought tested in this study.

Distributed SA was measured using Critical Decision Method (CDM) which were analysed using a thematic analysis and frequency of word count to produce propositional networks which reflects the ‘object-relation-subject’ patterns within the CDM (Salmon et al., 2009b; Klein, 2000). Propositional Networks as an analytical and representational tool for Distributed SA are discussed in detail in Salmon et al. (2009b).

2.4. Limitations

This study is not without its limitations; foremost of these is the weakness of a single experiment. Further studies, if similar in results, will strengthen the indicative results reported here. Administrating the SAGAT as a freeze-probe technique was not possible as the ELICIT software does not allow moderators to pause the game. It is therefore possible that our results have been confounded by too high a reliance on memory, leading to the low scores seen here. This effect was sought mediated by the immediate administration of the questionnaire upon ending the game. Other methods which may perhaps constitute a better fit with ELICIT may be; Situation Awareness Rating Scales (SARS; Waag and Houck, 1994), NASA TLX (Hart and Staveland; 1988, cited in Stanton et al., 2005) and Event Analysis of Systemic Team Work (EAST; Stanton, Baber and Harris, 2008). The findings presented here are merely indicative and further work should seek to explore the role of SA in network structures agility.

3. Results

Here we briefly present the results for the two conditions. Firstly, we look at the findings of relevance to Shared SA, the ELICIT measures of Identify, time and sharing behaviours. Finally, we consider Distributed SA.

3.1. Shared SA

The SAGAT probes were developed from the factoids provided in the game according to the three levels of SA described above. The highest possible score was 21 for both conditions. The individual SAGAT scores were calculated separately for each team member and a mean obtained. A score of 12.12 was obtained for the Hierarchical condition while 12.59 was obtained for the Edge condition (see figure 1 and 2), neither score more than just over half of the maximum score. It should be noted that there was one response missing in the Hierarchical condition.

Descriptive Statistics

	N	Mean
SAscore	16	12.12
Valid N (listwise)	16	

Figure 1: Hierarchical network structure's SAGAT score.

Descriptive Statistics

	N	Mean
SAscore	17	12.59
Valid N (listwise)	17	

Figure 2: Edge network structure's SAGAT score.

Contrary to expectation the difference between the two conditions is marginal. Indeed the slight difference might be wholly explained by the one missing response in the Hierarchical condition. A Mann-Whitney test was performed to investigate difference in SAGAT score between the two conditions. The Mann-Whitney of .559 exceeded the critical level for U at 0.05. Consequently we did not find a difference between Hierarchy and Edge for the SAGAT measure.

By way of contrast to the SAGAT score, a SART questionnaire was administered at the end of the game to allow individual subjects to rank their own SA. Here too we found little difference between the average SART score Hierarchical and Edge, 5.56 and 5.94 respectively. A Mann-Whitney test was performed to investigate difference in SART score between the two groups. The Mann-Whitney of .786 exceeded the critical level for U at 0.05. As such we did not find a difference between the groups. Figure 3 and 4 show the spread of the SART scores. Although there is more variation in terms of scores obtained these confirm the above finding.

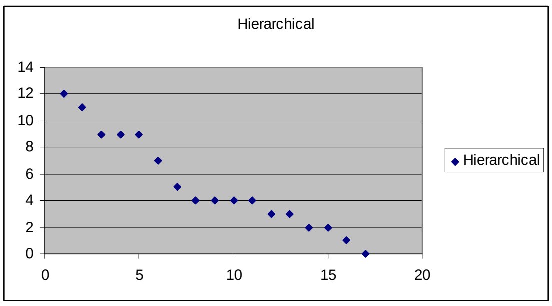

Figure 3: Spread of SART scores

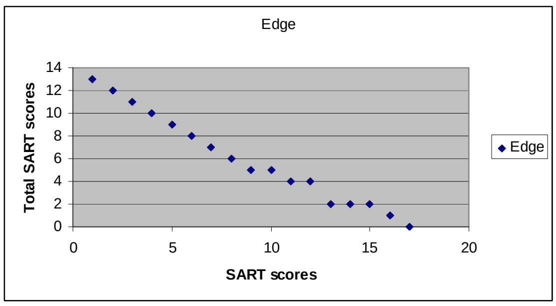

Figure 4: Spread of SART scores

3.2. ELICIT measures

In the Hierarchical condition the Cross-Team Coordinator correctly identified the solution (see Table 2); while in Edge three team members correctly identified the solution (see Table 3). We, therefore, found no difference in correct identify between the two conditions as both successfully completed their team task (only Cross-Team Coordinator could be expected to identify in the Hierarchical condition).

Table 2: Correct identify for the Hierarchical condition

	Strict Scoring
Number of Correct Ids	1 (Alex)
Earliest Correct Id	1881 sec
Correct Ids / Total Actions	0.001321004
Correct Ids / Time	0.00144648

Table 3: Correct identify for the Edge condition

	Strict Scoring
Number of Correct Ids	3
Earliest Correct Id	952 sec
Correct Ids / Total Actions	0.002714932
Correct Ids / Time	0.004619649

There was a difference, however, in the earliest correct identification which was at 952 seconds for the Edge condition. In contrast the Hierarchical conditions solution came almost twice as late at 1881 seconds.

Sharing behaviours were measured in terms of direct sharing of factoids between participants in each condition, posts on topic specific websites and pull from such websites by participants. The two conditions exhibited only a small difference in terms of number of posts; with 130 in the Edge condition compared to the 111 for the Hierarchical condition. There was considerably more direct sharing in the Hierarchical condition than in Edge, 231 against 48 respectively. In terms of pulls we found a larger number of pulls in the Edge condition, 747, than in the Hierarchical condition which had 167. See Table 4 for summary.

Information exchange	Hierarchy	Edge
Posts	130	111
Share	48	231
Pull	747	167
Total	925	509

Table 4: Summary table of information exchange

3.3. Distributed SA

The CDM responses were analysed using a thematic analysis and frequencies of words were counted. Figure 5 and 6 represent the frequency scores obtained and the cut-off point drawn for the words to be included in the propositional networks. For the Hierarchical condition the cut-off point was 4, hence no words mentioned fewer than 4 times were included. For the Edge condition the cut-off point was 5 individual listings.

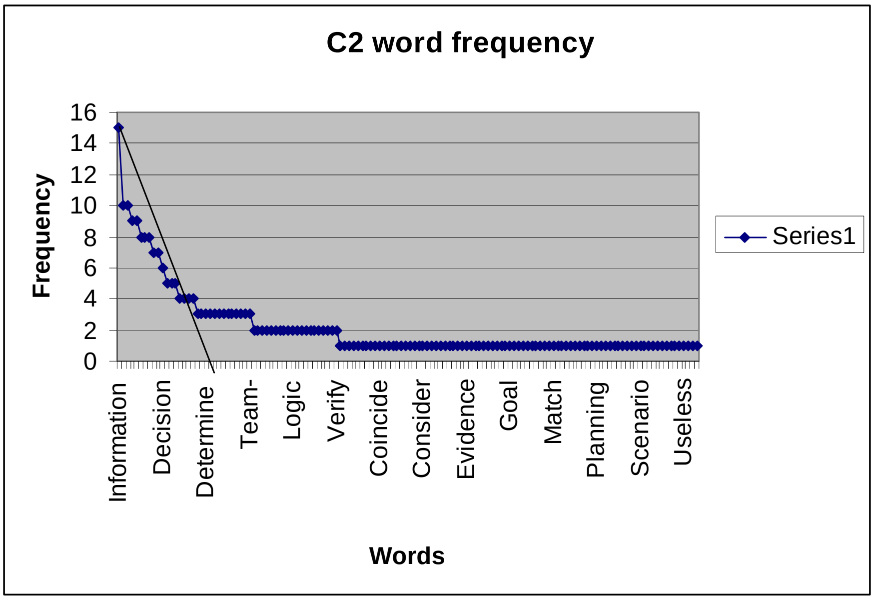

Figure 5: Frequency of words for the Hierarchical condition.

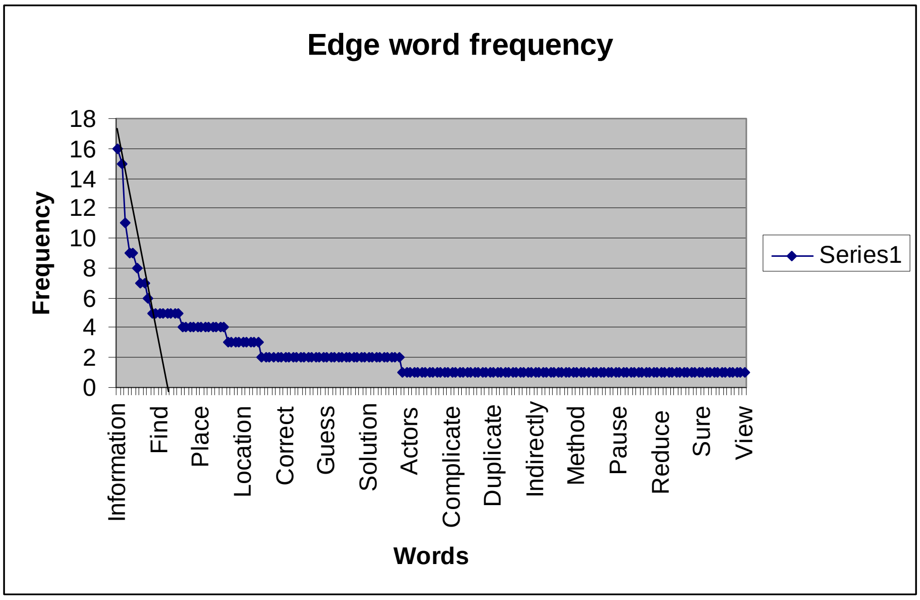

Figure 6: Frequency of words for the Edge condition.

Propositional networks have been put forward as a means to describe a systems SA, representing the information underlying a systems knowledge and relationship between these (Salmon et al., 2009). Figure 7 depicts the propositional network created of the subject>relation>object patterns in the CDM responses in the Hierarchical condition, Figure 8 for the Edge condition. The propositional network represents a systems level depiction of the Distributed SA contained within the network structure.

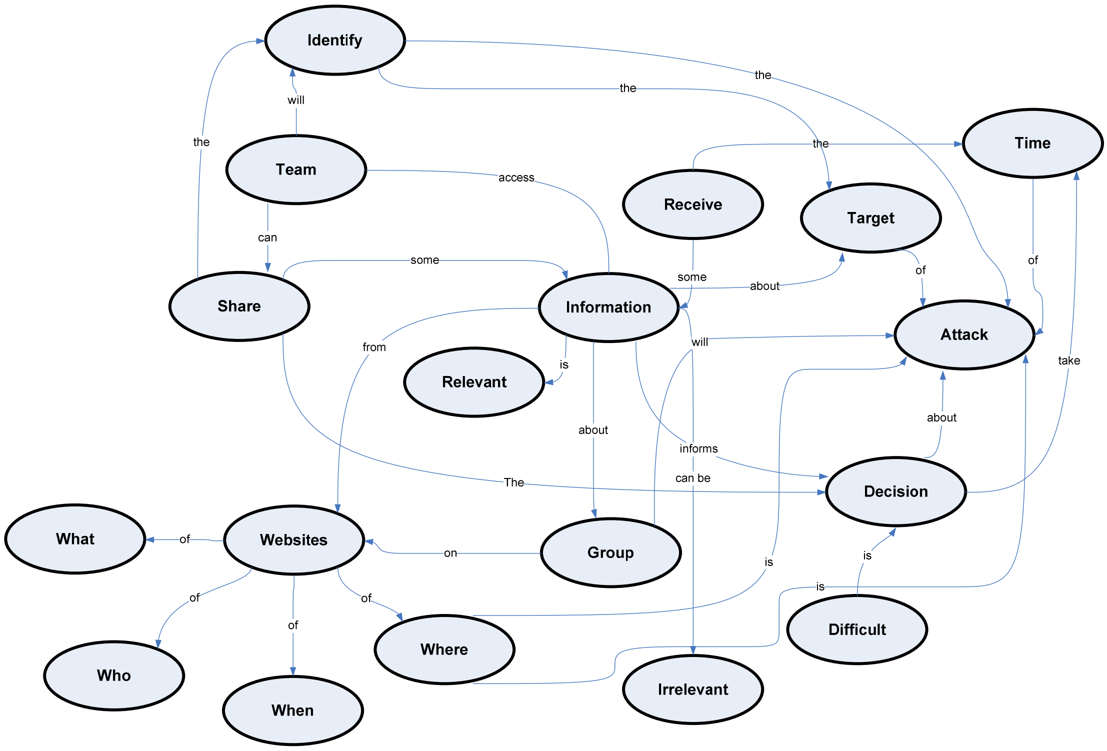

Figure 7: Propositional Network; DSA of Hierarchical condition

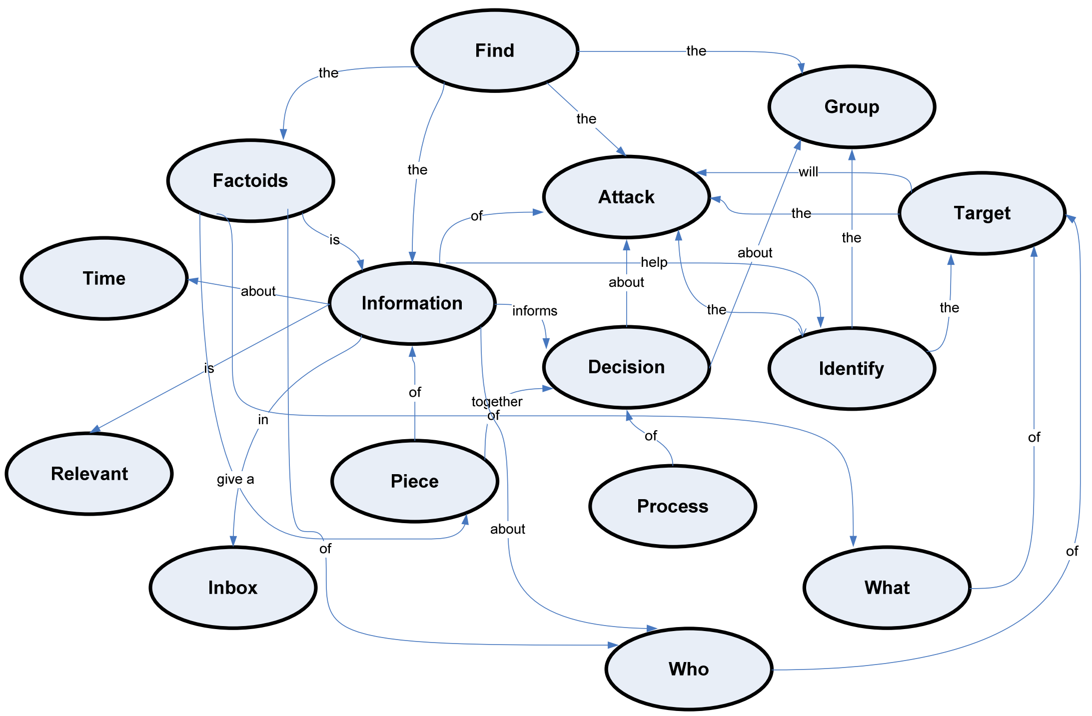

Figure 8: Propositional Network; DSA of Edge condition

Although the propositional networks contain some of the same information elements there are a number of different concepts which are exclusive to each network structure, for instance “receive” is only contained within the Hierarchical structure while process is unique to the Edge structure. The concepts relationships reflect the different ways in which the network structures utilise the information available and the knowledge each system contains. Whereas it was not possible to say there was a difference between the SA in the two conditions when considering Shared SA we can see that there is a clear difference between the Hierarchy and Edge conditions in terms of their Distributed SA. In the following we discuss the implications of these findings.

4. Discussion

We expected to find a difference between the Hierarchical and Edge conditions when analysing SA as Shared SA as measured by SAGAT and SART. However, the non-parametric tests and the near-equal means obtained for each Shared SA measure did not reveal any difference between the two network structures. Within the psychological school of thought Shared SA is understood as shared SA requirements for team members (Endsley, 1995). As such we would have expected the Edge organisation, in which all team members share the same team role and task responsibility, to obtain a high SAGAT score. This was not supported in our findings. Similarly, the low score obtained for the Hierarchical condition does not indicate a particularly high degree of overlap in SA requirements within this team.

We did find, however, some difference in the patterns of sharing behaviour between the two groups. This may indicate that although both networks successfully completed their task and identified the solution the manner in which they approached the process of problem solving differed. For instance, in the Edge network there were few direct shares but a high number of pulls from the respective intelligence web sites. Although no conclusive evidence exists it may appear as if the Edge network is more individual-oriented while the Hierarchical network structure appears more team-oriented in their task. The clear division of roles and task responsibility which is prevalent in the Hierarchy, but lacking in the Edge network, may account for these differences.

The systems approach, in contrast to the notion of team SA as being shared, argues that SA is an emergent property of collaborative systems. The qualitative findings represented in the propositional networks reflect such systems. The individual team member is only one part of this system and each has awareness which is different but compatible to that of other team members. According to Stanton et al. (2006) compatible awareness form the glue which holds the distributed system together. They argue further that Distributed SA is activated knowledge, which is activated at any time for a particular task within the system. The findings represented in the propositional networks show the summative knowledge contained within the network and the relational links between them show how these knowledge structures were activated at different points in the task performance. We therefore argue that both network structures exhibited Distributed SA.

Although no difference in SA was found between the Hierarchy and Edge conditions for Shared SA we did reveal a difference in Distributed SA. This is evident where knowledge items are held by one structure but not the other, such as Process which was held by the Edge network but not Hierarchy. The content of the propositional networks strengthen the pattern seen in the sharing behaviours. Conceptual items in the propositional network reflect a team-oriented approach for the Hierarchical structure and an individual-oriented approach for Edge where each team member seem to problem solve as if they were working alone. The relational links between concepts are also different in the two network structures, reflecting different paths of knowledge activation within the collaborative system. See Table 5 for a summary of key findings. Further work is needed to quantify these initial qualitative findings for firmer conclusions to be drawn.

Table 5: Summary of key findings

	Performance	Diagnostics		
Org type		SAGAT	SART	PN/SNA
Hierarchical	1881 sec	12.12	5.56	• Different content of information • Different activation of same knowledge
Edge	952 sec	12.59	5.94	• Different content of information • Different activation of same knowledge

In our opinion SA is vital to agility in network structures and we believe its operation in different network structures merits investigating. In particular we believe that the notion of Distributed SA should be explored as a function of agility. Understanding whether there are differences between the prevalence of SA in different network structures and the nature of that SA as being either Shared or Distributed will contribute to developing the field of command and control research.

5. Conclusion

This study showed little difference between the Hierarchy and the Edge networks when considering the SAGAT and SART results, suggesting that they were not sensitive to the differences of SA between the two network structures, whereas the Distributed SA method revealed qualitative differences in the underlying schemata of the teams in question. This suggests that allowing the participants to freely express the ways in which they make decisions, through an open-ended CDM questionnaire and then performing content analysis is more likely to reveal differences in distributed cognition and SA than a prefabricated set of probes and rating scales. This paper sheds some light on the difficulty of measuring SA quantitively in experimental designs, however, in applying alternative approaches such as Social Network Analysis and Propositional Networks we believe we highlight a method which may overcome these in measuring team SA in ELICIT studies as well as elsewhere. Further studies utilising the DSA framework measured with Social Network Analysis and Propositional Networks should be conducted to further investigate whether these reveal more of the differences between Hierarchical and Edge networks than those SA methods which have been more commonly used.

Acknowledgements

This work from the Human Factors Integration Defence Technology Centre was part-funded by the Human Sciences Domain of the UK Ministry of Defence Scientific Research Programme.

We would like to express our gratitude to the ELICIT community, in particular to Mary Ruddy of Parity Communications Inc. for her instruction in the ELICIT software platform, experiment materials and advise.

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