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FACULTY OF ENGINEERING AND THE ENVIRONMENT

Civil, Maritime and Environmental Engineering and Science Unit

Distributed Situation Awareness: Experimental Studies into Team Work

by

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ABSTRACT

FACULTY OF ENGINEERING AND THE ENVIRONMENT
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Doctor of Philosophy

DISTRIBUTED SITUATION AWARENESS: EXPERIMENTAL STUDIES INTO TEAM WORK

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For Command and Control teams Situation Awareness forms an important part of their ability to execute their tasks. It is therefore a crucial consideration in Command and Control systems to understand how best to support and design these systems. Despite a considerable amount of attention since the 1980s no consensus has yet been reached concerning the nature of team SA. Three schools of thought on SA: the Individualistic, the Engineering and the System Ergonomics, provide three different approaches to understanding the phenomenon of SA and its measurement. This thesis argues that the System Ergonomics school of thought, with the theory of Distributed SA, provides the most resilient approach to understanding team SA. This thesis advances and validates the theory of Distributed SA. A review of SA theory is presented, in which particular attention is given to Distributed SA. Drawing on the distributed cognition and systems theories Distributed SA takes the interaction between agents and their environment into account when exploring how SA emerges, followed by a review of measures utilised for assessing Distributed SA. The methods utilised in this work, namely the Critical Decision Method and Communications Analysis, are assessed in terms of their reliability and validity of eliciting Distributed SA. The findings suggested that methods to assess team SA can be tailored to collect data at different phases of activity. It was concluded that the Hierarchical Task Analysis may be applied before, Communication Analysis during and the Critical Decision Method after Command and Control activity. An experiment was performed to test the assumption that a relationship exists between organisational structure and team performance and between Distributed SA and team performance. Conclusive differences were found between different organisational structures and performance lending support to the literature. Distributed SA was found to be strongly correlated with good task performance and moderately negatively correlated with poor task performance. The relationship appeared to be mediated by organisational structure. Furthermore, a series of case studies are used to explore the components of Distributed SA, i.e. transactional and compatible SA. The analysis showed that more effective teams were characterised by a high volume of communications and had a different pattern of transactions compared to less effective teams. The findings are used to contribute to the existing debate concerning team SA and to advance the theory of Distributed SA.

Keywords: *Situation Awareness, Distributed Situation Awareness, Teamwork, Network Analysis, Command and Control, Collaborative Systems.*

Contents

Tables

Figures

Glossary

ASI	Air Speed Indicator
B-L	Bavelas-Leavitt Centrality
C2	Command and Control
CADMID	Concept, Assessment, Demonstration, Manufacture, In-service and Disposal
CCRP	Command and Control Research Programme (US Army)
CDM	Critical Decision Method
CIS	Communication Information Systems
DCDC	Development, Concepts and Doctrine Centre (MoD)
DSA	Distributed Situation Awareness
DSR	Distributed Situationally Relevant
ECC	Emergency Command Centre
HTA	Hierarchical Task Analysis
MD	McDonnell Douglas
MEU	Marine Expeditionary Unit
MoD	Ministry of Defence
N.S.	Not Significant
NATO	North Atlantic Treaty Organization
NCW	Network Centric Warfare
NEC	Network Enabled Capability
OIM	Offshore Installation Manager
OSD	Operator Sequence Diagram
PF	Pilot Flying
PN	Propositional Network
PNF	Pilot Not Flying
S.D.	Standard Deviation
SA	Situation Awareness
SAGAT	Situation Awareness Global Assessment Technique
SART	Situation Awareness Rating Technique
SME	Subject Matter Expert
SNA	Social Network Analysis
TRC	Task relevant communications
UK	United Kingdom
US	United States of America

DECLARATION OF AUTHORSHIP

I, Linda Johnstone Sørensen

declare that the thesis entitled

'Distributed Situation Awareness: Experimental Studies into Team Work'

and the work presented in the thesis are both my own, and have been generated by me as the result of my own original research. I confirm that:

- this work was done wholly or mainly while in candidature for a research degree at this University;
- where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
- where I have consulted the published work of others, this is always clearly attributed;
- where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
- I have acknowledged all main sources of help;
- where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
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For the two Ann Maries

1 Introduction

1.1 Background

Situation Awareness (SA) has gained significant attention since the late 1980s and has been attributed as an influential factor in successful and unsuccessful task performance both for individuals and teams (Endsley, 1995; Patrick and Morgan, 2010; Stanton et al., 2006a; Salmon et al., 2009a; Salmon et al., 2009b). Its importance in individual and team performance has led to research efforts seeking to understand the phenomenon and its role in performance. In particular, the impact of SA in complex environments have been of interest to the research and practitioner community in recent years (e.g. Stanton et al, 2006a; Stanton et al., 2008; Salmon et al., 2008; Salmon et al., 2009a; Salmon et al., 2009b; Patrick et al., 2006; Patrick and Morgan, 2010; Artman and Garbis, 1998; Artman, 2000; Endsley, 1995). Military Command and Control (C2) teams, in particular, are faced with challenges which, it has been argued, are vulnerable to loss of SA (Salmon et al., 2009b; Stanton et al., 2009a). These challenges are exemplified by the following extract of a private communication concerning the lessons learned from an operation in Iraq in March of 2003, a Centcom J5 Planner and UK officer, Colonel (Rtd) F.J. Chedham shared the following via email:

> "As part of the operation to secure the Al Faw Peninsula in South East Iraq during March 2003, US Marines of the 15th Marine Expeditionary Unit (MEU) crossed the border under the cover of darkness from Kuwait. Heading north, they bypassed the central port town of Umm Qasr and advanced into the areas of the docks. Their mission was to secure the facilities before they could be destroyed by retreating Iraqi forces in order that they could be used by the invading coalition forces for the storage of supplies and the distribution of relief aid. The 15th MEU was under command of the British Three Commando Brigade Royal Marines. The main bodies of the Commando Brigade were to be deployed from the east by air using Chinook helicopters. The weather closed in significantly during the US Marines deployment, reducing visibility and degrading their sophisticated night vision equipment. The weather situation also had a major impact on air operations and the British forces had already lost a Sea King helicopter resulting in the fatalities of the crew and passengers.
>
> The US Marine force was equipped with sophisticated communication information systems (CIS) which were superior to the electronic systems held by British forces but the equipment were also incompatible. The

> British system lacked the electronic bandwidth to receive data, specifically GIS data which was critical to ensure that the heavily armed formations were aware of each other's presence and could coordinate intentions. The poor flying weather required the plan to be changed at very short notice and only after the US forces had committed to cross border operations. The change of plan by the British forces was relayed to the US forces but the lack of data bandwidth meant that the British commander was only able to provide a general overview of his revised intentions to a junior US commander who was involved in heavy close combat against an elusive opponent in conditions of highly reduced visibility.
>
> Eventually, six hours later elements of the British Forces began to arrive within a brief flying window. They did so using a different approach corridor than the one previously defined, closing upon a US force which had been in contact for five hours in darkness. The impacts of stress, adrenalin and combat engagement caused the force to disperse into decentralised groups and lose situation awareness." (Personal communication with Colonel Chedham, 2012).

The email communication outlined above highlights the complexities of the environments faced by military C2 teams. Whilst the operation described above had a successful ending; operations undertaken at different times, under similarly difficult conditions, have led to the loss of life for both serving forces and civilians through incidents of fratricide (e.g. Bundy, 1994, Simmons, 2003). Frequently C2 teams work in distributed manners, both in terms of time and space, handling vast amounts of information and utilising advanced technology to support their decision making. Achieving and maintaining SA has been identified as an important mechanism to enable such teams to navigate the difficult informational terrain they are faced with.

Despite considerable research into the phenomenon since the 1980s, contention remains in the Human Factors community concerning the nature of SA. This is particularly true with regards to team SA where three schools of thought offer opposing views of the concept; the Individualistic, the Engineering and the System Ergonomics schools of thought. The notions of team SA as being either Shared or Distributed are most popular. Shared SA considers SA as being shared by and identical to other team members (Endsley, 1995; Endsley, 1999a). Distributed SA, on the other hand, considers that SA arises from the interaction between team members and is not identical but compatible (Stanton et al., 2006a; Salmon et al., 2009a). Given this contention many have called for a greater understanding of team SA, particularly in relation to which is the most appropriate way of modelling and explaining team SA (e.g.

Artman and Garbis, 1998; Salmon et al., 2008; Gorman et al., 2006; Salmon et al., 2009c). With increased understanding comes the opportunity to support and enhance SA to benefit individuals, teams and wider society. The concept of team SA therefore warrants further investigation.

The research presented in this thesis sought to resolve some of the issues surrounding the concept of team SA whilst validating and advancing the theory of Distributed SA. This was done systematically by means of experiments to achieve the following six research objectives:

1. To contribute to the debate surrounding the concept of SA by establishing which model of SA bears most relevance to the understanding of SA in teams; shared SA or Distributed SA.
2. To establish whether there is a relationship between Distributed SA and the organisational structure of teams..
3. To establish the way in which Distributed SA emerges in different organisational structures.
4. To test whether Distributed SA is correlated with team performance.
5. To explore different types of SA transactions and how these contribute to performance in teams.
6. To explore compatible and incompatible transactions in teams.

Section 1.2. outlines the structure of this thesis and the chapters in which the research objectives are addressed.

1.2 Thesis structure

This thesis has been structured in a chronological manner reflecting the research as it developed. The thesis comprises nine chapters.

The first two chapters of the thesis consider the most prevalent theories of SA and their associated measurement techniques. The findings from these resulted in a narrowing of the research focus, from all theories concerning team SA to the theory of Distributed SA. Chapters four and five explore methodological issues related to the measurement of Distributed SA in teams whilst chapters six, seven and eight present empirical tests performed to further develop the theory of Distributed SA. Each chapter is outlined in brief below:

Chapter Two: Contrasting Three Approaches to SA – a literature review.

This chapter presents a comprehensive literature review which sets out three schools of thought concerning SA: the Individualistic, the Engineering and the System Ergonomics. An analytical exercise contrasts each school of thought in terms of its ability to describe the flight processes of descent and approach between two pilots and their instruments (originally described by Hutchins, 1995b). The aim of this chapter is to present the reader with the key ideas surrounding the nature of SA and the associated strengths and weaknesses of each approach. In so doing, this chapter seeks to answer the first research objective. The analysis illustrates how the Individualistic and Engineering schools of thought emphasise distinct features of either the individual or the world as fundamental to the development of SA.

Chapter Three: Is SA Shared or Distributed in Team Work? – an experimental study

This chapter builds on the comparison presented in chapter two by considering two models from the Individualistic and System Ergonomics schools of thought in more detail, namely the three-level model of SA (Endsley, 1995) and the Distributed Situation Awareness model (Stanton et al., 2006a), with their associated measurement techniques. This chapter, therefore, introduces SA measurement. An experimental study is presented which applies the measures from both perspectives on SA to two different teams, in order to test each measure in terms of their ability to reveal SA. The experimental teams were constructed so that whilst each team performed the same task they were required to do so under different working conditions; working in either a hierarchy or in a fully networked team.

Chapter Four: When can Distributed SA be Assessed: Before, During or After Command and Control Activity? – a methods review

This chapter considers three data collection techniques used in the assessment of Distributed SA and considers when these are best applied. Fourteen criteria categorised into three areas: Distributed SA relevant criteria, C2 relevant criteria and research methodological criteria, are applied in the comparison of the data collection techniques. Of the fourteen criteria six were Distributed SA related (i.e. interaction, assessment of compatible SA, description of SA transactions, emergent Distributed SA, the ability to consider human versus technical agents and input into design), four were related to C2 criteria (i.e. invasiveness, tools needed, time taken to administer and access requirements) and four were research methodological criteria (i.e. reliability, validity, training, resources required, and theoretical underpinnings). It is argued that measuring Distributed SA in C2 environments requires unique attention, as the ability to understand weaknesses in the development of Distributed SA in C2 teams, can influence the adoption of technologies and training of such teams to improve battlefield performance. The strengths and weaknesses of each of the three data collection measures and their use prior to, during or after C2 activity are considered.

Chapter Five: Inter-rater Reliability and Criterion-referenced Validity of Measures of Distributed SA – an empirical study

The utilisation of Distributed SA in the design of systems or teams requires that reliable and valid measures of assessment are available to researchers and practitioners. This chapter therefore builds on the preceding chapter by considering the inter-rater reliability and criterion-referenced validity of two data collection techniques (i.e. the Critical Decision Method and Communication Analysis) which feed into the network analysis method (e.g. concept maps) used to assess Distributed SA. These methods require a significant time and resource investment as the analysis process requires a high level of researcher input. To alleviate these weaknesses software tools have been developed, such as Leximancer™, which automates the extraction of words into codes and concept maps. The software tools must be capable of providing highly reliable analysis. The inter-rater reliability study presented in Chapter Five therefore assessed the reliability of the outputs of the Leximancer™ tool and the concept map methodology. A test of validity was performed by creating Hierarchical Task Analysis of four experimental tasks and generating a "prototypical" concept map. The prototypical concept map was compared against the observed concept maps for each of the five experimental teams on each task.

Chapter Six: How Distributed Situational Awareness is Mediated by Organisational Structure and Correlated with Task Success – an experimental study

This chapter considers the assumption, prevalent in the literature, that there is a relationship between SA and task performance (Patrick and Morgan, 2010; Endsley, 1995). An experimental design was devised for which a sample of 300 participants was recruited. Using the sociotechnical theory description of different organisational structures the participants were randomly allocated to one of five organisational structures (e.g. the chain, the y, the circle, the wheel and the all-connected). Each team consisted of five participants and each experimental condition (organisational structure), had 12 teams. In total the experiment was conducted using 60 teams. Each team collaborated to play eight strategy games where the aim was to take as many red players as possible without taking non-red players. The teams' communications were transcribed and analysed using network analysis and concept maps were developed. Team performance was analysed using the Signal Detection paradigm (Stanton and Young, 1999a; Dekker, 2012).

Chapter Seven: Transactional SA in Teams: The Glue which Holds Teams Together – a case study

Teams are often utilised in complex environments and understanding the manner in which they interact is therefore of importance to the research and practitioner communities. In particular, the manner in which teams interact and share information to achieve task success is important to understand the phenomenon of Distributed SA. This chapter explored the interactions which take place within teams which have performed well and compared this to teams which have performed less well. The study utilised the distributed cognition, transactional memory and Distributed SA theories to explore the communications observed in the two team types. Distributed cognition argues that cognition emerges from the interactions between people and their environment. Transactional memory is defined as 'the knowing who knows what' in a team, meaning that in order to access information it is necessary to know who, or what, holds the required information in the first place (Mitchell and Nicholas, 2006). Further, this chapter considered the quality of the teams' SA transactions and the impact of these on the teams' performance.

Chapter Eight: Exploring Compatible and Incompatible Transactions in Teams – Implications for Distributed SA – an exploratory case study
This chapter sets out to explore the nature of compatible and incompatible transactions in teams whilst applying the ideas of schemata as regulators of behaviour to the workings of a team. An exploratory study was devised in which the communication transcripts from the experimental study described in Chapter 6 was analysed. Schemata and in particular the notions of contention scheduling (Norman and Shallice, 1986), schema errors and the Perceptual Cycle Model (Niesser, 1976) supports the ideas presented in the Distributed SA approach by explaining the way in which previous experience and knowledge amassed by each team member may shape their interaction with the world. The chapter considered whether compatible and incompatible SA transactions impact on the development and activation of schema. It was theorised that such transactions mitigate between conflicting schemata through a process of assimilation and accommodation whereby schemata are added to and changed. The application of the Perceptual Cycle Model to teams' dynamic exploration of, interaction with and adaptation to their environment was also considered.

Chapter nine: Key contributions and future research
This chapter concludes the doctoral research by discussing the main findings and their implications for Distributed SA in teams and a discussion of the limitations of the research is given. The findings are further considered in relation to the original aims of the research and the contributions made to knowledge are highlighted along with areas for future work.

1.3 Contribution to Knowledge

This thesis contributes to knowledge in a number of ways. In particular, significant contributions are made to the literature concerning the nature of SA. A contribution was made through a review of three approaches to the explanation of SA. Contributions are also made through an empirical test of two models of team SA; Shared and Distributed SA. Conclusions drawn from this empirical study point to the particular usefulness of applying the theory of Distributed SA to the study of team SA. A review of data collection techniques available to assess Distributed SA provided guidance for the tailoring of assessment to phases of team activity. A further contribution was made to the measurement of Distributed SA by providing support for the reliability and validity of the network analysis method and associated data collection techniques used to assess Distributed SA. These methodological advancements lend support to researchers and practitioners who seek to understand Distributed SA in teams. A contribution was made to the field of small group research through the application of social network analysis and network analysis methods to reveal differences between teams and assess Distributed SA.

Contributions are made through an empirical study to assess the assumption that organisational structure and team performance and Distributed SA and performance are associated (Salas et al., 1995; Endsley, 1995; Endsley, 1999a; Endsley, 1999b; Kaber and Endsley, 2004). Distributed SA was found to be strongly correlated with good task performance and moderately negatively correlated with poor task performance. This finding presents a significant contribution to the literature and SA research.

Further, a relationship was found between team's organisational structure and team performance providing a contribution to the fields of team research and organisational theory by lending support to the literature that has argued that a relationship exists between organisational structure and team performance (e.g. Salmon et al., 2009a; Endsley, 2000). These findings further contribute to the fields of military command and control, safety research and team training, fields which have considered whether an optimal team structure for performance exists (Alberts and Hayes, 2003; Alberts and Hayes, 2006; Walker et al., 2009a; Walker et al., 2009b; Stammers and Hallam, 1985; Patrick and Morgan, 2010).

This thesis, furthermore, presents a contribution to knowledge by validating and advancing the theory of Distributed SA as evidenced in the exploration of meaningful communicative acts, i.e. SA transactions, and their role in team performance. A contribution was made to Schema Theory by showing that the concepts of the theory can be applied to explore teams.

2 Literature Review: Contrasting Three Approaches to SA

2.1 Introduction

There is a growing body of literature calling for a more complete development of the theoretical foundation for the phenomenon of SA (Burns et al., 2008; Rousseau et al., 2004). A number of studies have been conducted to identify the characteristics of SA and understand how it can be enhanced (Stanton and Young, 1999b; Patrick et al., 2006; Hledik, 2009). Patrick and Morgan (2010) discussed the developments in this area to date in a comprehensive review, as do Salmon et al. (2008). Endsley et al. (2003)have found that the way in which information is presented to the operator through an interface influences SA by determining how much information can be processed in a limited space of time. Advances have been achieved in terms of understanding the phenomenon of SA, how it manifests itself across a range of work contexts and how it can be measured, although as of yet there is no consensus in the field with regards to how SA should be understood (Salmon et al., 2008). Similarly, several authors have encouraged the design of systems to support SA of different users through a SA requirements analysis, rather than an overview analysis of generic roles (Malone and Schapp, 2002; Salmon et al., 2010; Salmon et al., 2009b). This design principle is not often adhered to (Salmon et al., 2009c). Rather, systems appear to be designed without an understanding of what information is needed by whom and how it will be used by different actors. Some guidelines have been developed to support the design of systems and displays (e.g. Endsley, 1999a: Endsley et al., 2003; Salmon et al., 2009b), yet these do not appear to be adhered to in the literature as guides to inform the design of systems or displays to support the creation and maintenance of SA in teams (McGuiness and Ebbage, 2002). A recent paper by Stanton et al. (2010a) argues that there are three main schools of thought considering the phenomenon of SA; the Individualistic, the Engineering and the System Ergonomics. It appears that the lack of utilisation of appropriate design guidelines to support SA is caused by the fragmented understanding of SA as advocated by the Individualistic and Engineering schools respectively. Stanton et al. (2010a) take the view that SA is best understood as the interaction between people and their environment and artefacts within it, as proposed by the System Ergonomics approach. As such, support for SA is required at a systems level and must take an interactive approach to design; taking into account the individual, the environment, and the artefacts as well as the interaction that emerges between them. Endsley et al. (2003) sought to encourage this in their eight design guidelines, such as:

"presenting level 2 information directly to the operator" (p. 83).

Although these guidelines are useful they separate the individual agents and the artefacts they interact with. This separation amounts to 'thinking in silos' which ignores the interaction between the agent and the artefacts in the world. By applying each SA perspective to a case study, this chapter argues that it is the interaction that should be the focus of attention for design efforts to support SA. This is achieved by the analysis of the interactions between two pilots and the cockpit instruments they utilise to perform their tasks. It is shown that each school of thought on SA leads to fundamentally different suggestions for design (Baber and Stanton, 1996).

First, the theoretical foundations of the three schools are discussed; second, the literature which directly addresses display design as relevant for SA is presented. Thirdly, the process of descent and approach of an aircraft is analysed from the perspective of the three schools in order to ascertain the design implication of each; and finally, future directions for research and display design aimed at supporting SA are suggested.

2.2 Setting the scene for SA

Attempts at defining SA have given rise to a variety of views. Stanton et al. (2010a) categorised these broadly into three schools of thought. They firstly described the Individualistic approach whereby SA is seen as a psychological phenomenon which resides entirely in the agent's mind. Secondly, they presented the Engineering school of thought where it is argued that SA resides in the world, and finally, the System Ergonomics approach in which SA is considered as an emergent property arising from an agent's interaction with their environment (Stanton et al., 2010a; Stanton et al., 2006a). This final school of thought sees SA as distributed cognition. Hence, the System Ergonomics approach does not separate the notion that SA resides in the mind from the world, but rather sees the two as interdependent. This chapter builds on the discussion of the three theoretical positions presented by Stanton et al. (2010a). This chapter argues that each school of thought gives rise to different explanations of SA related activity and that these consequently lead to different ways of designing for, and supporting, SA. Indeed, they also give rise to different approaches to the measurement of SA, a topic which has been covered in detail elsewhere (see for instance Salmon et al., 2009c). Establishing a boundary for the analysis of SA around either people or artefacts in the world artificially divides up a system, analysis of either alone does not adequately explain the phenomenon of SA nor does it produce appropriate support (Salmon et al., 2008; Salmon et al., 2010). The Individualistic and the Engineering schools do have value; however. In the following section the contributions of these two schools of thought are contrasted with that of the System Ergonomics school of thought.

2.2.1 SA as an individualistic phenomenon

The Individualistic school of thought considers SA as an individual characteristic, contained within the mind of an operator (Stanton et al., 2010a). Endsley's (1995) three-level model has received most interest within this approach. Endsley (1995) stated that SA is:

> "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).

As such, SA is perceived to consist of three separate levels, perception, comprehension, and projection respectively (Endsley, 1995). By piecing together the data inherent in the situation (perception, i.e. level 1) and understanding it (comprehension, i.e. level 2) the individual can make assumptions about the future (projection, i.e. level 3) and act accordingly. Endsley et al. (2003) argues that without a sound development of level 1 and level 2 the individual cannot achieve level 3 SA.

Endsley's (1995) definition is often favoured in the literature due to its well-defined levels which allow for precise measurement when one thinks of SA as three distinct and separate levels (Salmon et al., 2008). This model therefore offers an uncomplicated explanation for SA. However, it is not without criticism. Literature in the decision making research domain for instance, suggests that expert decision makers have what can be considered to be SA, without being able to explain what elements of a situation they perceived to build their understanding of the situation (Rousseau et al., 2004). For these experts it is not possible to divide their SA into the three levels in a meaningful way. The three-level model does not explain situations where SA is a continuous process, nor does it usefully extend to explain team SA. Endsley (1995; 2000) presented team SA as Shared SA where individual team members share the same SA requirements. Although it is tempting to add individual team members' SA together to provide a representation of team SA it has been widely argued that team SA is more than the sum of its parts (Salas et al., 1995; Salmon et al., 2008; Masys, 2005; Stanton et al., 2009c).

The Individualistic school of thought emphasises the importance of the psychological qualities of the individual to achieve SA. Sarter and Woods (1991), for instance considers 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 conceptualisation of how elements are to be understood, that is to say 'are explained', and how future states can be predicted (Banbury et al., 2004). Bedny and Meister (1999) argued that SA phenomena can only be understood as part of cognitive activity that is intensely dynamic. Similarly Artman (2000) referred to SA as:

> "active construction of a situation model" (p5).

This emphasises the individual as being an active mediator in developing and maintaining SA.

Given the above, the position taken by advocates of the Individualistic school of thought is that several cognitive processes underlie the development of SA and indeed the ability to maintain SA is challenged by limitations in cognitive processing (Smith and Hancock, 1995). The most important of these are attention and memory, schemata, mental models, goal-driven processing and experience. The function of cognitive factors in achieving SA, and their limitations, have been adequately described elsewhere (e.g. Endsley, 1995; Smith and Hancock, 1995; Endsley, 2000; Sowa, 2006). Below, the Engineering school of thought is presented, which places the emphasis on the environment as opposed to the individual in acquiring and maintaining SA.

2.2.2 SA as situated in the world

The Engineering school of thought asserts that SA resides in physical phenomena (Stanton et al., 2010a). This is evident in the way designers and lay people discuss artefacts in the environment as 'having' SA. These views are in stark contrast to the views held by the Individualistic school of thought, as it is the artefact itself that is the holder of SA, and not the individual. Jenkins et al (2009b) found that military helicopter pilots referred to their displays as containing their SA. Before commencing flight the pilots were required to mark their route on a display within the cockpit, this included visual references, such as, symbols for rivers, power lines and churches. Jenkins et al. (2009b) found that it was these visual references the pilots referred to as their SA.

Similarly, engineers and operators talk of 'setting SA' in instruments and displays. They ensure the technical equipment is set to 'take care of' SA so that they do not have to expend effort ensuring that SA is adequate while performing their tasks. Instead, they trust the settings on the instrument to alert them to relevant changes in the environment. For example, the pilots look for incongruity between the visual references on their display and the environment outside of the cockpit as they handle the aircraft (Stanton et al., 2010a; Jenkins et al., 2009a; Jenkins et al., 2009b). The individual is involved, not as the driver of SA related activity, but as the recipient of SA relevant information.

Traditional design methods and principles which address physical and perceptual characteristics of system components align with this view. A desire to design systems and technologies that counter the limitations of the fallible human remains strong in the Engineering domain. In contrast to the two approaches described above the following section presents an approach to SA which does not separate the individual and its environment but rather sees SA as the interaction between these.

2.2.3 SA as en emergent property

The System Ergonomics school of thought takes a systems approach to the study of SA. This perspective is influenced by distributed cognition (Baber and Stanton, 1996: Stanton et al., 2009b) and sociotechnical theory (Stanton et al., 2009a). Stanton et al. (2006) proposed a theory of Distributed SA which consisted of four theoretical concepts: Schema Theory, genotype and phenotype schema, Perceptual Cycle Model of cognition, and the distributed cognition approach. The theory of Distributed SA takes a systems approach to SA and considers SA as an emergent property of collaborative systems (Salmon et al., 2008; Salmon et al., 2009b). Distributed SA, according to Salmon et al. (2008) 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).

The authors further explained that a system is comprised of both people and artefacts and together they form a "joint cognitive system" (Hollnagel, 2001) and that cognitive processes emerge from and are distributed across this system (Salmon et al., 2008). This means that cognition is achieved through coordination between system units and that awareness is distributed across those human and technological agents involved in collaborative activity (Salmon et al., 2010; Salmon et al., 2008; Salmon et al., 2009b). An artefact, such as a display, may contain 'awareness' for a specific task such as speed or temperature, whereas the individual retains the 'awareness' of when to apply this information. In this way, the artefact offloads from the individual the need to have awareness for the speed or temperature element of a system. This example also highlights the point made by Salmon et al. (2008, 2009b; 2010); that cognition is achieved through coordination, as it is only when an individual engages with the artefacts in the environment that complete SA can be achieved.

Stanton et al. (2006a) suggested that individual SA represents the state of the individual's perceptual cycle. Similarly, Smith and Hancock (1995) draw on Neisser's

(1976) Perceptual Cycle Model in explaining how SA works. 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).

Stanton et al. (2006a) do not discount the individual's importance in SA but they contend that the individual forms only one part of the explanation. They explained that an individual possess genotype schemata that are triggered by the task relevant nature of task performance (Salmon et al., 2009b). 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., 2009b).

Rather than SA being shared among team members, Stanton et al. (2006a) considered team members to possess unique but compatible portions of awareness. Compatible awareness holds distributed systems together (Stanton et al., 2006a; Stanton et al., 2009b; Salmon et al., 2009b; Salmon et al., 2010). Agents within collaborative systems enhance each other's awareness through SA transactions, such as exchange of SA relevant information (Salmon et al., 2009b). Both parties use the information for their own ends, integrate into their own schemata, and interpret individually in light of their own tasks and goals (Salmon et al., 2008; Salmon et al., 2009b). Thus, SA in distributed teams is enhanced through transactions; such as information sharing, rather than being shared and each agent's SA is updated via SA transactions (Salmon et al., 2009b). According to Stanton et al. (2006a) Distributed SA can be defined 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 their activities and goals (Salmon et al., 2008). In a similar vein, Banks and Millward (2009) argued that a mental model need not be contained within a single individual; rather it may be distributed in a group. Each person therefore holds part of the mental model (Banks and Millward, 2009). 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 theory therefore transcends the fragmented views offered by the Individualistic and the Engineering schools of thought by providing the means to view:

> "the system as a whole, through a consideration of the information held by the artefacts and people and the way in which they interact" (Stanton et al., 2010a, p.5).

In the following section the descent and approach phase of flight in a McDonnell Douglas, MD-80, as presented by Hutchins (1995b), is considered through the 'eyes' of the three main schools of thought. This example was chosen as a means of theoretical analysis as it allows for a consideration of each school's main arguments. The aim of this analysis is not only to show the differences of the three stances but also to indicate the implications of each for consideration of SA related design.

2.3 Distributed cognition in the cockpit

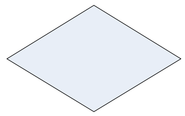
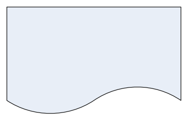
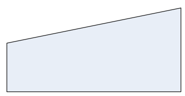
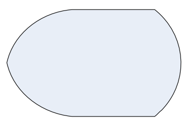
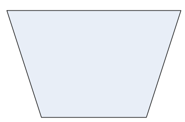
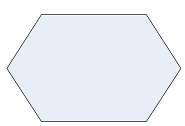
Hutchins (1995b) detailed the process of an aircraft's descent and approach for landing in his discussion of distributed cognition in the cockpit. This article was influential to the development of the Distributed SA theory within the System Ergonomics approach. The process is presented in an Operator Sequence Diagram (OSD) which is used to:

> "graphically describe activity and any interaction between agents in a network" (Stanton et al., 2005, p.115).

An OSD was created here and was sectioned chronologically into four parts. This was validated by a commercial aircraft pilot with 32 years of experience flying the MD-80, among other aircrafts. Table 2.1 presents the OSD key.

The process of approach and descent is divided into four phases. In the first phase the landing data is prepared, as can be seen in Figure 2.1. The Pilot Not Flying (PNF) checks the aircraft weight on the gross weight display and selects the correct speed card from the speed card booklet, as indicated by the aircraft weight. The selected speed card is then placed on the airspeed indicator (ASI) for future reference.

Table 2.1 OSD key

	Process
	Decision
	Document
	Manual input
	Display
	Manual Operation
	Terminator
	Connector
	Direct data
	Delay

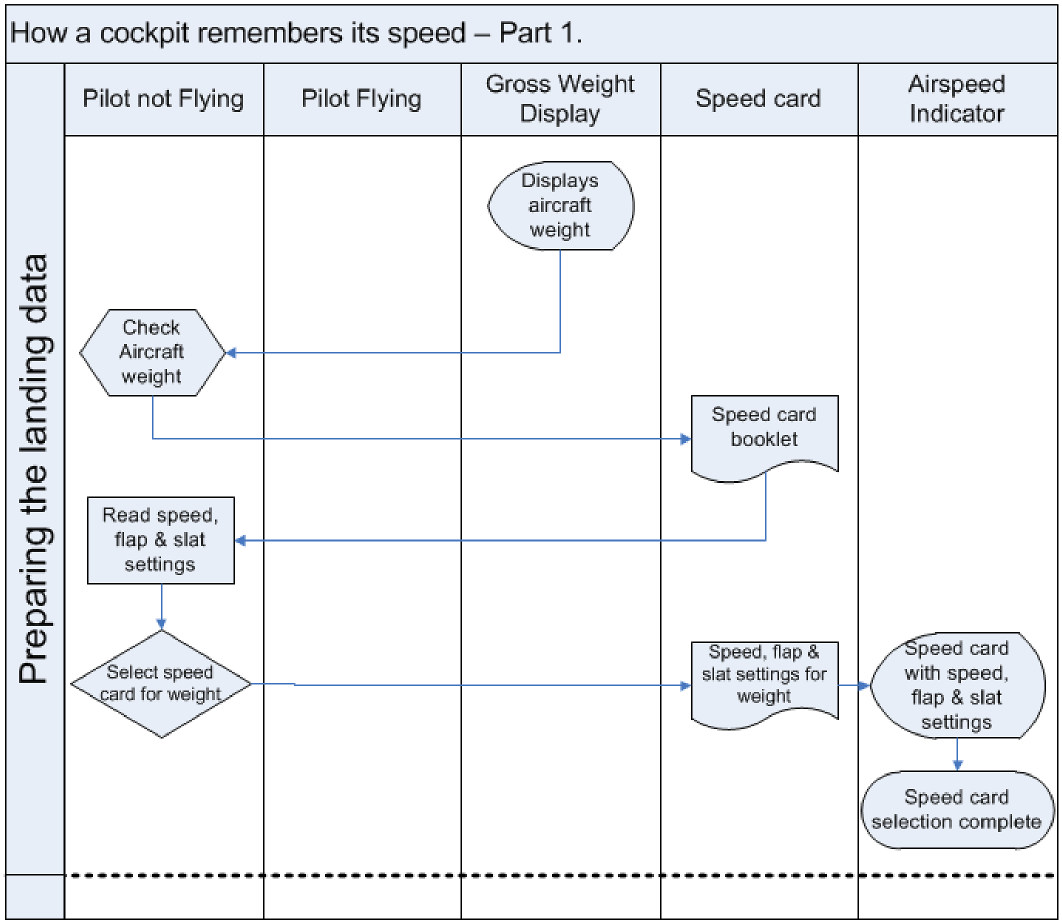


Figure 2.1. Distributed cognition in the cockpit, part 1, preparation of landing data.

In the second phase, represented in Figure 2.2, the speed bugs are set on the ASI next to the values on the speed card which are relevant to the safe descent of the aircraft.

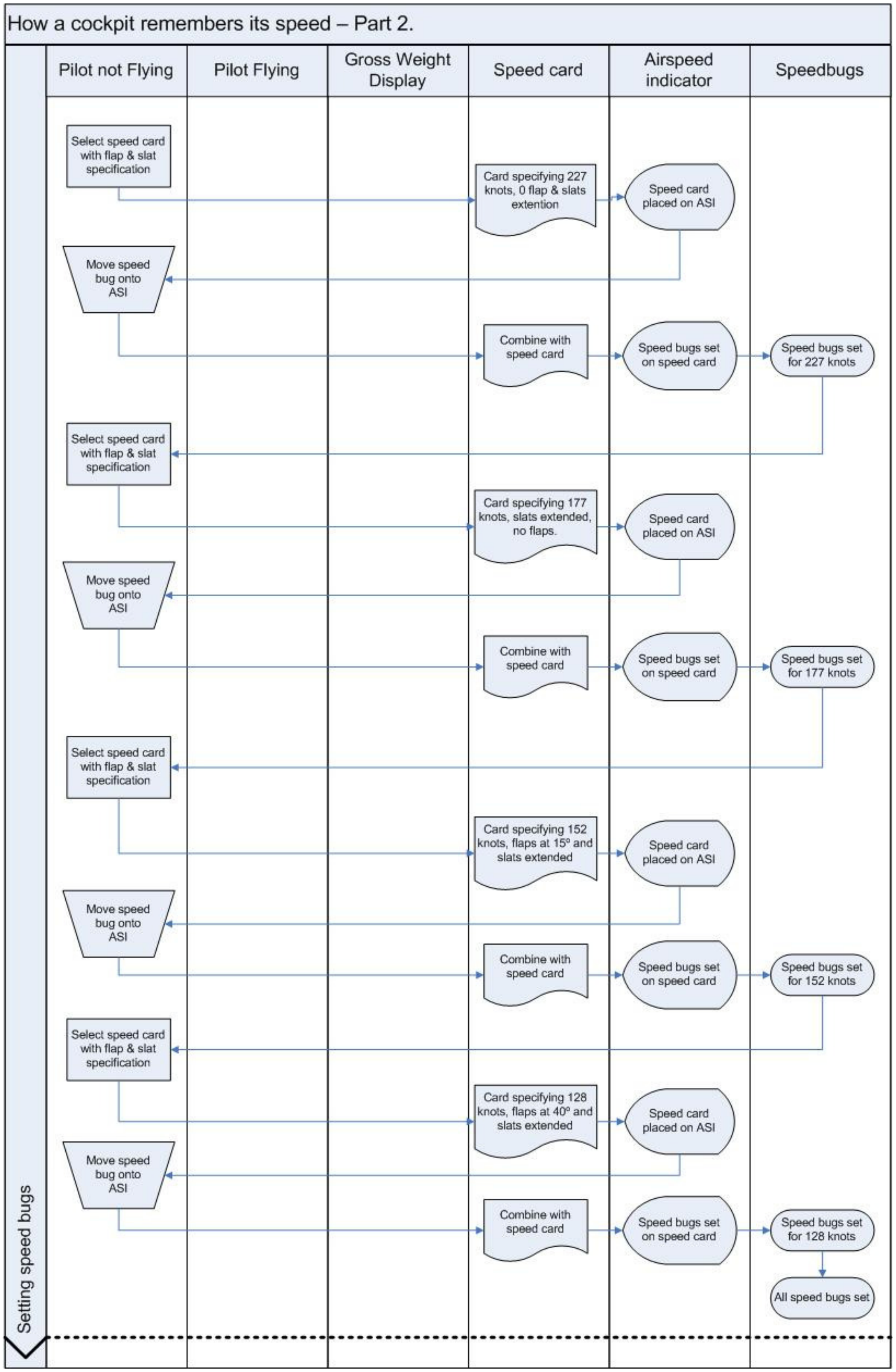


Figure 2.2. Distributed cognition in the cockpit, part 2, setting of speed bugs.

Firstly, the PNF takes the speed card previously selected and at 227 knots, selects nil flaps and slat extension, combines this with the speed card and moves the card onto the ASI. The PNF then moves on to the next speed and place a speed bug on the ASI by the 177 knots mark, nil flaps and full slats extension. This step is repeated for a third speed where the speed bug is set at the 152 knots mark and for 15º flap extension with fully extended slats. In the final step the PNF places a speed bug on the ASI by 128 knots with 40º and full slat extension. This completes the process of setting speed bugs. An example of an ASI with speed bugs set can be seen in Figure 2.3.

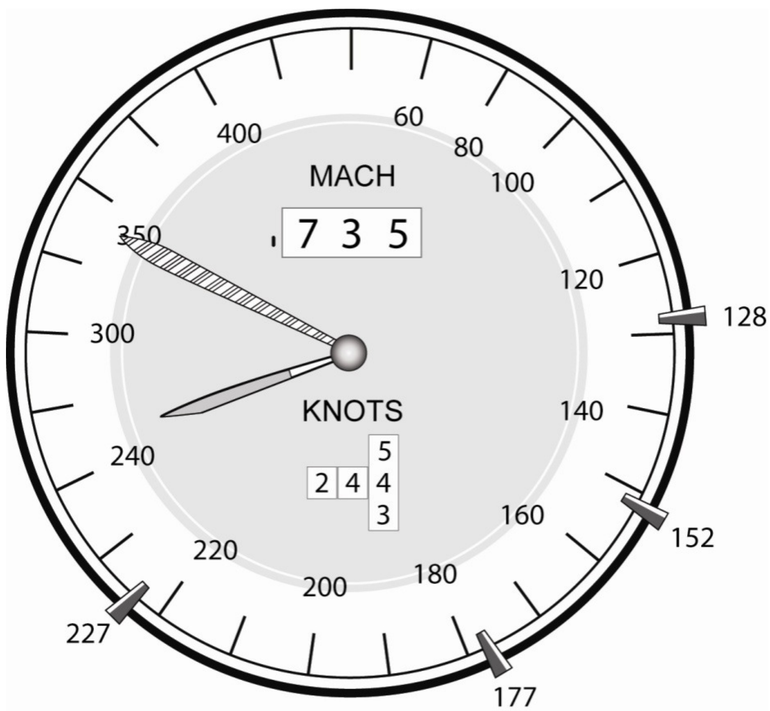


Figure 2.3. Speed bugs set on ASI, adapted from Hutchins (1995b).

In phase three, as can be seen in Figure 2.4, the speed card and speed bug settings are cross-checked by the two pilots. The PNF consults the speed card for its settings and calls these out to the Pilot Flying (PF). The PF in turn checks the values on the speed card, then the speed bugs, and reads these back to the PNF. The PF then uses the speed bug settings to configure the flap and slats settings according to the values indicated on the speed card. This completes the cross-check.

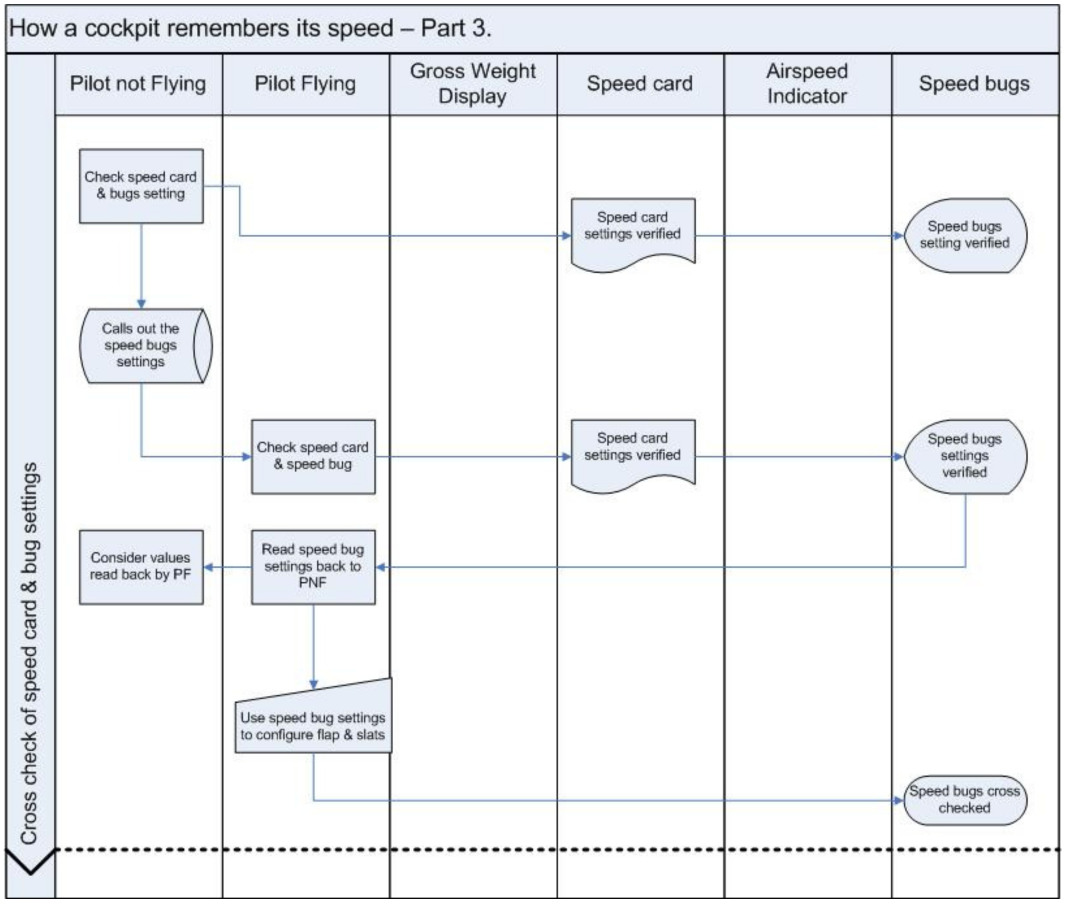


Figure 2.4. Distributed cognition in the cockpit, part 3, cross check of speed card and bug settings.

The fourth phase, the descent and final approach, represents how the PNF and the PF reduce the aircraft speed and altitude as they descend for landing, as represented in Figure 2.5 and Figure 2.6. The PNF checks the altitude indicator and when it is at 10.000 feet they call this value out to the PF who considers the value and reduces the speed according to the values set on the speed card, firstly to 227 knots. The PF moves the throttle and waits for the needle on the ASI to reach the desired speed bug. The speed is used to select flap and slat setting, as predetermined on the speed card, in this case no changes are required. The PF nonetheless calls out the labels for the flap and slat settings to the PNF. The PNF monitors the altitude indicator and when this reads 7000 feet calls out the value to the PF who then considers the altitude value against the necessary speed on the speed card and reduces the speed to 177 knots by moving the throttle. When the needle on the ASI reaches the next speed bug the PF calls the value out to the PNF along with the required flap and slat settings, in this case fully extended slats but no extension to the flaps. The PNF adjusts the position of the flaps and slats to that effect and resumes monitoring of the altitude. As the altitude reaches 1000 feet the PNF calls this out to the PF who once again considers the value against the speed and commences reduction of speed to 152 knots by moving the throttle. Once the needle has reached the speed bug at 152 knots the PF calls out the label for flaps extended to 15º and slats fully extended to the PNF, who adjusts the flap and slat handle accordingly. When the altitude is at 500 feet the PNF calls the value out to the PF who determines the right speed reduction, 128 knots, and moves the throttle. When the needle is by the speed bug at 128 knots the PF calls out the required flap and slat settings which are set by the PNF to 40º flap extension and full slat extension. This completes the flap and slat setting for the descent and final approach.

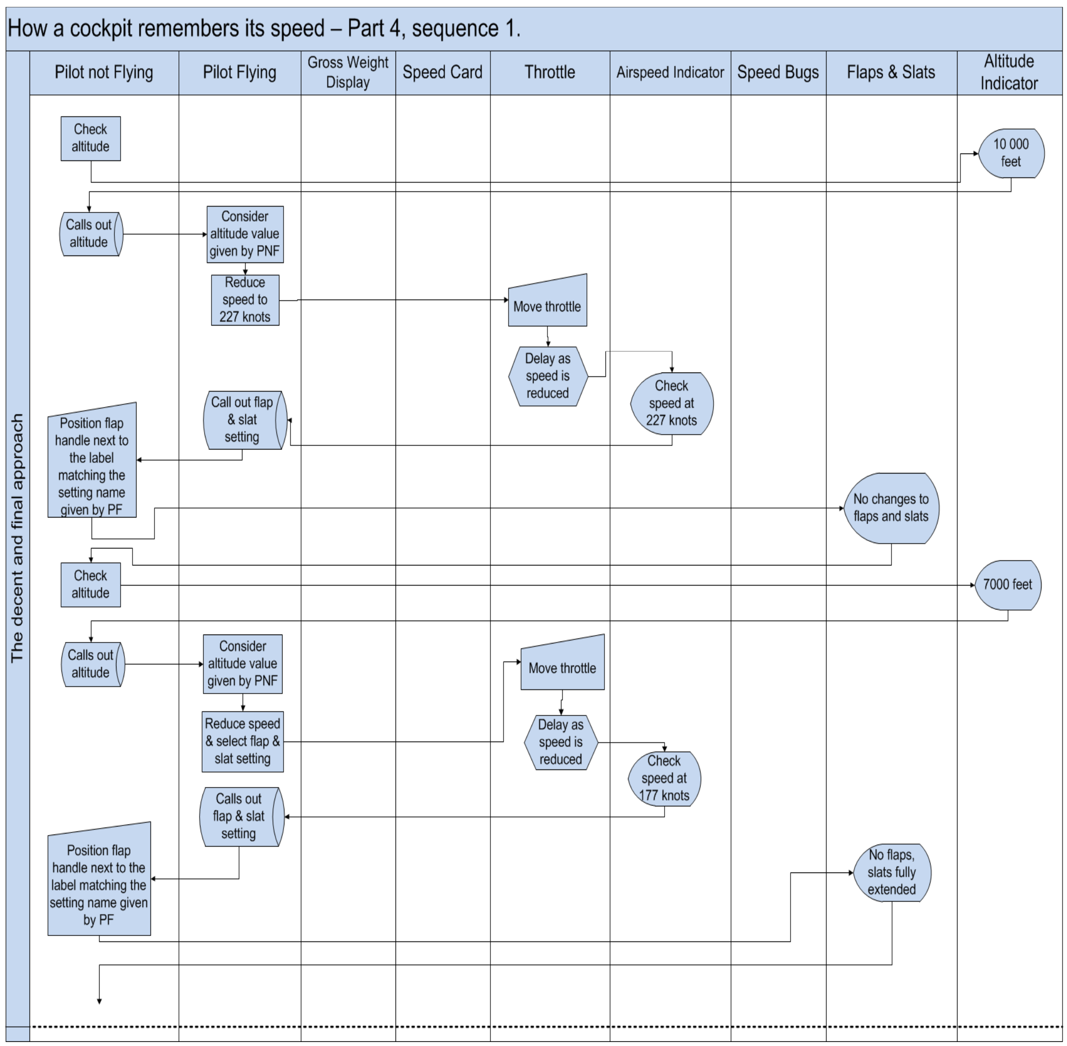


Figure 2.5. Distributed cognition in the cockpit, part 4, sequence 1, the descent and final approach.

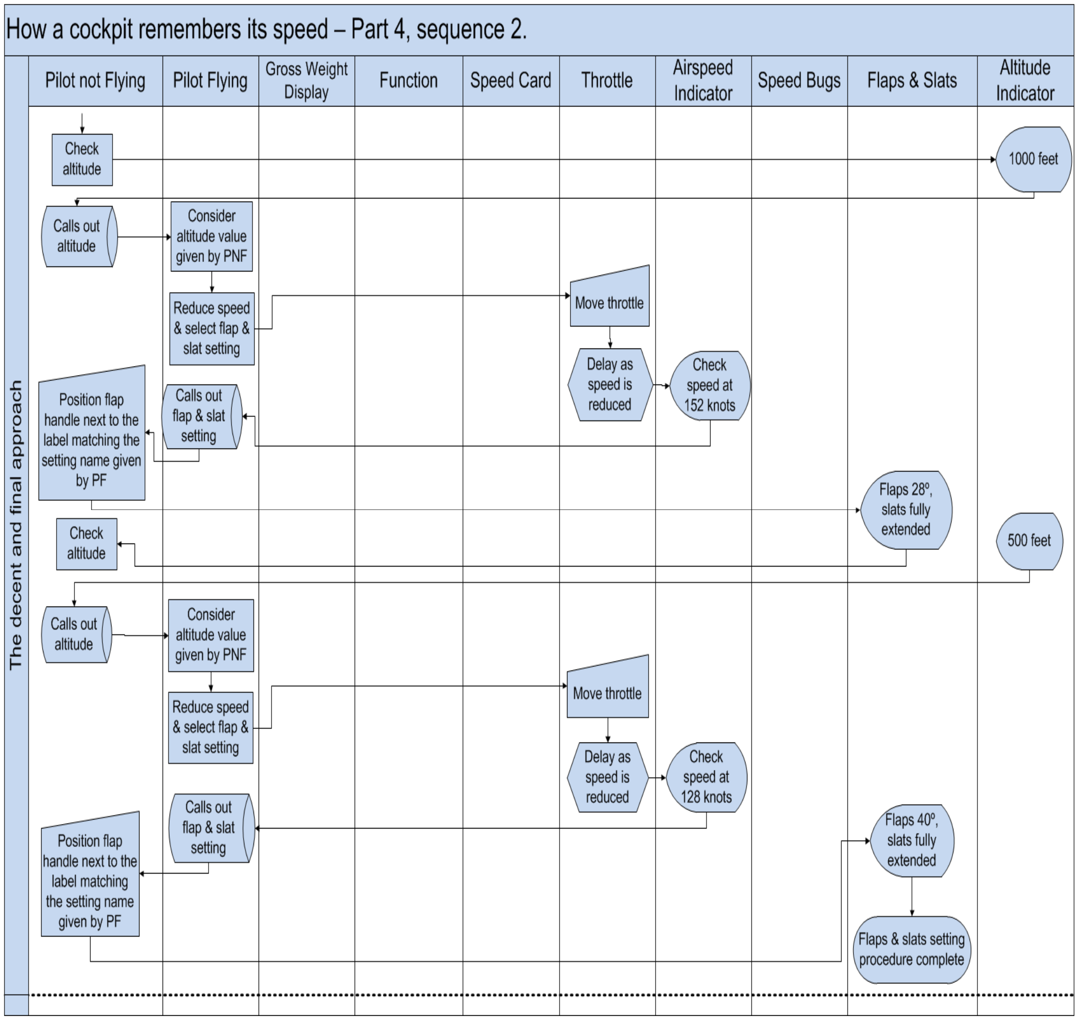


Figure 2.6. Distributed cognition in the cockpit, part 4, sequence 2, the descent and final approach.

Below, the process of descent and approach is analysed from the perspectives of the three schools of thought; firstly in terms of the Individualistic school of thought.

2.4 Individualistic approach to SA

Figure 2.1 shows how the PNF prepares the landing data. The view advocated by the Individualistic approach suggests that SA is held in the mind of the individual operator. As such the PNF is required to develop a mental model of the correct speed in conjunction with the current aircraft weight, and must remember these crucial pieces of information to achieve SA. When applying Endsley's (1995) framework to the process portrayed, the displayed aircraft weight provides the elements, or data, in the environment which is perceived. This is level 1 SA of the model. The correct selection of a speed card allows the PNF to comprehend the relevance of the data perceived in relation to the task of landing the aircraft. This is level 2 SA. Subsequently, the mental model formed provides the opportunity to appropriately project future system changes and what actions will be required by the PNF in order to safely descend for landing. In other words, the PNF projects what appropriate reductions of speed should take place in order to comply with aviation safety guidelines. This is level 3 SA.

Similarly, if Figure 2.3 is considered, the process of setting speed bugs on the speed card continues to inform the mental model created and strengthens the PNF's ability to project appropriate speed for descent, approach and ultimately, landing. Consequently advocates of the Individualistic approach speak of individuals as 'having' SA (Sarter and Woods, 1991; Endsley, 1995; Endsley, 1999a; Endsley, 1999b). According to this view the PNF 'has' SA in part 1, 2, 3 and 4 of the descent and approach process, whereas the PF 'has' SA for the speed cards only in part 3 (see Figure 2.4). Within the Individualistic approach, team SA is explained as:

> "the degree to which every team member possesses the situation awareness required for his or her responsibilities" (Endsley, 1995, p.31).

An important aspect of team SA is shared SA (Endsley and Jones, 2001; Endsley et al., 2003). Endsley and Jones (2001) referred to shared SA as the level of overlap in common SA elements between team members. SA can be shared when team members perform tasks which have the same SA requirements; however, where team members perform individual tasks their SA remains individual. Intuitively one might assume that the SA requirements for the PF and the PNF would be largely similar, however, when studying Figure 2.4 in detail it is clear that the only aspect of the task which is shared is verifying the speed card values.

Contrary to the notion of SA as residing within the mind of an individual, as indicated above, the Engineering school places the emphasis on the artefacts present in the cockpit. Below the Engineering school of thought is applied to analyse the process of descent and approach.

2.5 Engineering approach to SA

By taking an Engineering approach to SA it is found that, in the process described by Hutchins (1995b), those factors which are of relevance to SA are the gross weight display, speed card, airspeed indicator, speed bugs, flaps and slats and altitude indicator. Each artefact contains vital SA information and arguably they present information in the form in which it is being used, hence as described in Stanton et al. (2010) the artefacts displays SA directly. Stanton and Young (1999a) stated that SA is:

"achieved by integrating technologies to provide users with access to information based on their circumstances" (p.2).

As such, when the PNF has selected the speed card indicated by the aircrafts weight, placed the bugs aligned with the relevant speeds and placed this on the airspeed indicator, it is the airspeed indicator which 'has' SA. This is supported by Ackerman (2002) who described artefacts as bringing SA information to individual, and by DeMeis (2012) who presented technologies as containing SA (as cited in Stanton et al., 2010a).

While the above does not discount the individual's part in the process of landing the aircraft, the role of the individual is not to achieve SA but to receive SA from the artefacts. When the aircraft reaches descent and final approach (see Figure 2.5) the airspeed indicator with the assembled speed card and speed bugs directs the PF and PNF to reduce the speed with the throttle and adjust the flaps and slats according to the present altitude. This can be taken to support the view that it is the artefacts which hold SA, not the pilots. They are following a prescribed pattern of behaviour in accordance with the instrument readings.

Both the Individualistic and the Engineering school of thought contain valuable contributions to understanding SA; however, considering the individual and artefacts in isolation does not adequately explain the phenomenon. In contrast, the System Ergonomics approach takes a holistic approach to explain SA and considers the interaction between the individual, the artefacts and the context within which they exist.

2.6 Systems approach to SA

Stanton et al (2006a) argued, as does Salmon et al (2008), that each agent within a system plays a critical role in the development and maintenance of other agent's SA. Figure 2.5 shows how the process of descent and approach is distributed between the PNF, PF and the artefacts in the cockpit. Neither pilot alone, nor artefacts, holds adequate SA to safely land the aircraft. Smith and Hancock (1995) argued convincingly that SA does not reside in the person's mind or in the world but through the person's interaction with the world. Hutchins (1995b) explained that the representations in use, which are inside the cockpit, still remain outside the heads of the pilots. These thoughts are founded on the distributed cognition theory which considers that joint cognitive systems comprise the people in the system and the artefacts they use (Salmon et al., 2008). Artman and Garbis (1998) asserted that cognition, and therefore SA, is achieved through coordination between elements of the system. The cockpit should therefore be analysed as a whole, as a distributed system. Indeed, Hutchins (1995b) argued that memory for the speeds and the accompanying actions required by each speed to ensure safe descent is not contained by the pilots. Rather the pilots utilise the artefacts to store memory for the speed in the environment and draw on these when they are required. Memory for speed is therefore distributed between the two pilots and the artefacts in the cockpit. Hutchins (1995b) emphasised the interaction of people with each other and the physical structures in the environment as the fundamental point of inquiry to understand cognition in complex environments. This does not discount the individual, but places the individual, rightly, into the wider context within which he or she acts.

Similarly, Stanton et al. (2006a) argued that SA emerges from the interaction of people, artefacts and their environment. The pilots' requests and receives information from each other while also interacting with the artefacts, initially manually when setting the speed card and speed bugs and later as visual representations guiding their actions. The cross-check activity described in Figure 2.3 can be explained, not as an expression of shared SA, but as SA transactions. The PF and the PNF exchange SA relevant information with regards to the speed card and bug settings to ensure the correct values have been selected. During final approach, as represented in Figure 2.5, the PNF will call out changes in altitude which prompts the PF to push the throttle to reduce speed and call out the flap and slat settings appropriate when the required speed is reached. The flap and slat settings are then manually set by the PNF. This interdependent process shows that the PF is not aware of altitude or flap and slat handling, while the PNF is not aware at this point of the speed card reading or speed bugs or the aircrafts throttle (e.g. the aircrafts accelerator). The interdependence reflects the compatible nature of SA. Rather than being shared, which would suggest that the pilots have identical SA, it is clear that the pilots hold different but compatible SA. The PF is not required to hold exact awareness of altitude or flap and slat handling as he or she is not directly dealing with these, however, the PF is fundamentally aware of the importance of these to the approach. In turn the PNF, while not being aware of the throttle or the speed card for the purpose of approach is aware of the PF's handling of these. Both develop SA which is different but compatible with the other (Stanton et al., 2006a).

Stanton et al. (2010a) argued that compatibility binds sociotechnical systems together. When presented with the same information people will have different representations of it. This is because the information will be linked in different ways with other information to produce schemata for each individual (Stanton et al, 2010a). This demonstrates that ownership of SA is not held in the world or within the minds of people but is held by the system as an emergent property of its subsystems interaction. A summary of all the analyses is presented in Table 2.2, 2.3, 2.4 and 2.5 below.

Table 2.2. Summary of analysis; illustrations of the product of analysis using any of the three theoretical frameworks.

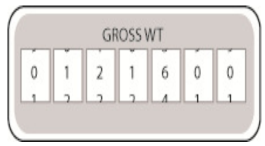
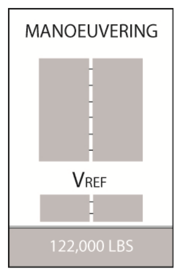
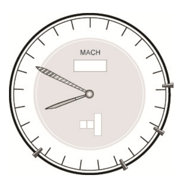
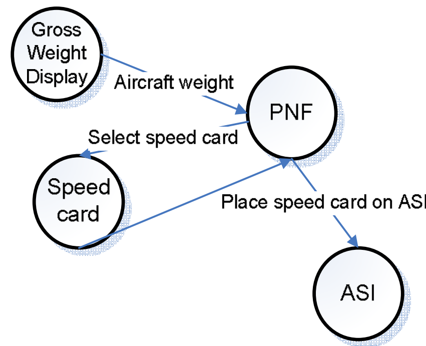
	Approaches to SA		
Phase of flight	**Individualistic**	**Engineering**	**System Ergonomics**
Preparing the landing data	<u>Level 1 SA</u> PNF: Aircraft weight <u>Level 2 SA</u> PNF: Selection of appropriate speed card <u>Level 3 SA</u> PNF: Anticipation of speed bugs settings	Gross weight display  Speed card  Airspeed indicator 	

Table 2.3. Summary of analysis: illustrations of the product of analysis using any of the three theoretical frameworks.

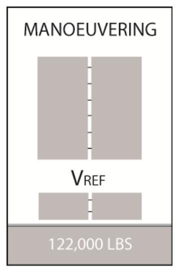
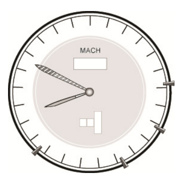
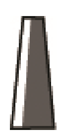
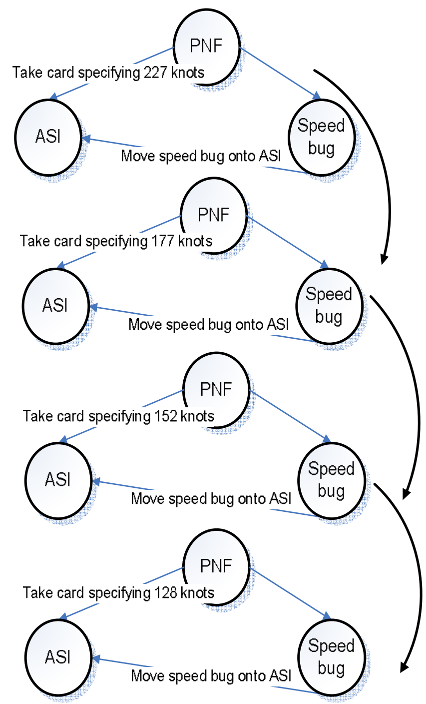
	Approaches to SA		
Phase of flight	**Individualistic**	**Engineering**	**System Ergonomics**
Setting speed bugs	<u>Level 1 SA</u> PNF: Speed card, airspeed indicator. <u>Level 2 SA</u> PNF: Placing speed bugs by correct speed as indicated by the aircraft weight and speed card. <u>Level 3 SA</u> PNF: Anticipation of the use of speed card and speed bugs for flap and slat setting.	Speed card  Airspeed indicator  Speed bug 	

Table 2.4. Summary of analysis; illustrations of the product of analysis using any of the three theoretical frameworks.

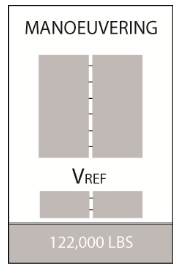
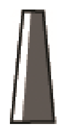
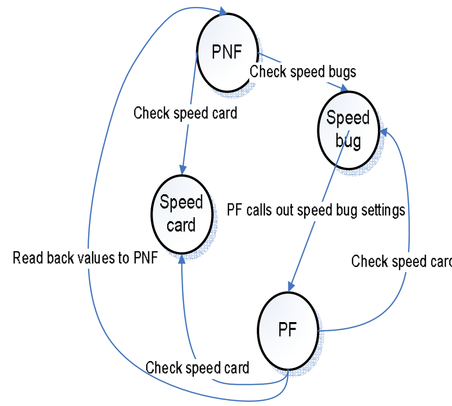
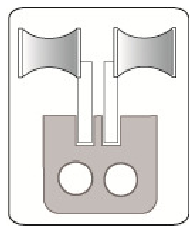
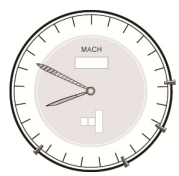
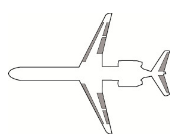
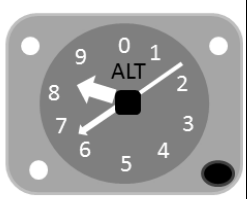
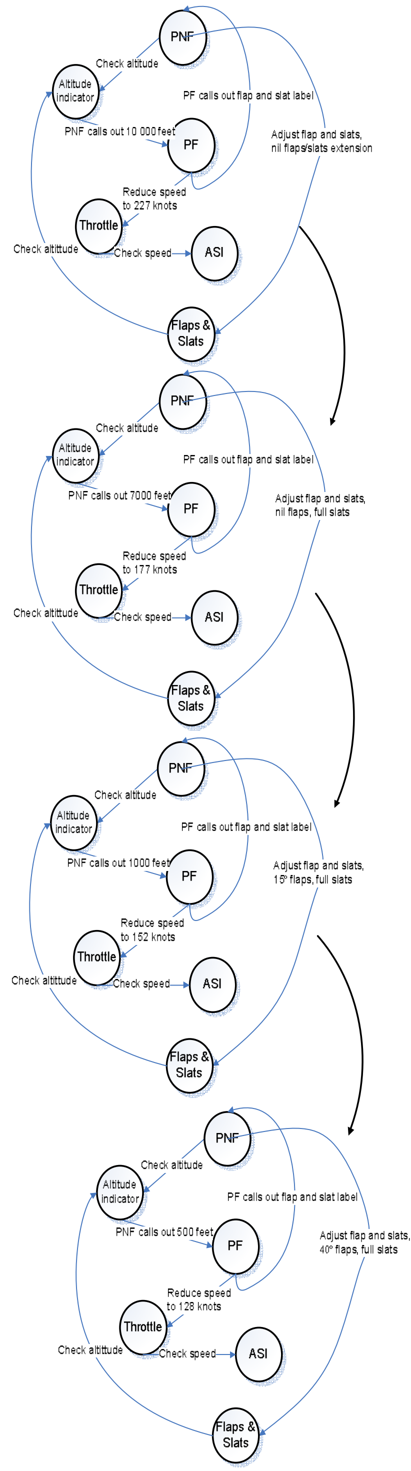
	Approaches to SA		
Phase of flight	**Individualistic**	**Engineering**	**System Ergonomics**
Cross-check of speed card and speed bug settings	<u>Level 1 SA</u> PNF: Speed card and speed bugs. PF: Speed card and speed bugs. <u>Level 2 SA</u> PNF: Considers the speed bug values seen against those read back from PF for inconsistencies. PF: Considers the speed bug values called out by the PNF against the speed card, looks for inconsistencies. <u>Level 3 SA</u> PNF: Anticipate use of speed bugs for flap and slat settings. PF: Anticipate use of speed bugs for reduction of speed.	Speed card  Speed bugs 	

Table 2.5. Illustration of the analysis outcome provided by the three theoretical frameworks.

	Approaches to SA		
Phase of flight	**Individualistic**	**Engineering**	**System Ergonomics**
Descent and final approach	<u>Level 1 SA</u> PNF: Altitude indicator, flaps and slats PF: Throttle, ASI <u>Level 2 SA</u> PNF: Relevance of flap and slat setting name called out by PF for adjusting the flaps and slats manually. PF: Relevance of altitude called out by PNF to speed reduction by using the throttle. <u>Level 3 SA</u> PNF: Anticipation of further adjustment of flap and slats as aircraft descends for landing. PF: Anticipation of further speed and altitude reductions as aircraft descends for landing.	Throttle  Airspeed indicator  Flaps & Slats  Altitude indicator 	

The three perspectives on SA consequently give rise to different principles for design to support SA; in the following these differences are highlighted.

2.7 Discussion

This chapter has analysed the process of descent and approach using the three main schools of SA to highlight the ways in which SA is explained. This chapter has argued that SA emerges from and is best understood as the interaction between people, artefacts and their environment, i.e. through the System Ergonomics school of thought. As such SA is a distributed property, not fully contained within either the individual or the environment, which emerges from interaction (Stanton et al., 2006a; Stanton et al., 2010a). Although the Individualistic and the Engineering school offer valuable contributions to the understanding of SA this review has shown that SA can only be fully understood as a Systems Ergonomic phenomenon.

This is further highlighted in that the three schools give rise to differing approaches to support and design for SA. The Individualistic approach places the emphasis on the cognitive properties of SA and suggests design guidelines which counter the limitations of human cognition, such as limitations of memory and attention, while drawing on the cognitive mechanisms of schemata and mental models to mitigate these. This is exemplified in a study by McCarley et al. (2002) who developed a computational model of SA to predict pilot errors. They reported results that indicated success in predicting improved performance associated with display augmentations, particularly with regards to the effects of visibility, distraction and degraded information quality.

Designs aimed at supporting team SA has, to a large extent, focused on shared displays to support the development of shared SA. Endsley and Jones (2001) suggested the use of large screens that are viewable from around the room or across electronic information sharing devices such as the internet. This approach advocates using abstracted shared displays where the information presented is the same to all team members (Endsley and Jones, 2001).

The Engineering notion of SA gives rise to new technology and interfaces which aim to contain all the SA relevant information for a specific task. Displays, such as computer screens, projected images and writing boards allow information to be present for all team members so that they may extract the information they need when they need it (Skyttner, 2001). For instance, DeMeis (2012) suggested that Ground Proximity Warning Systems provide SA information to help avoid controlled flight into terrain. Thus the technology alerts the operators of discrepancies between actual and desired system states to prompt the operators to act to re-establish equilibrium.

There are distinct similarities between the notion held by Endsley et al. (2003) that display design should directly present SA relevant information to individuals and teams, and those held by the Ergonomics school of thought. Endsley et al. (2003) for instance, highlighted the importance of displays as a tool with which the individual is provided with the perceptual elements of the situation and is enabled to comprehend it. In this way the display provides the means to establish SA. Similarly, the Engineering school of thought maintains that the awareness is entirely contained within the artefact regardless of whether there is an individual present or not. Both approaches emphasised the role of displays as a tool for SA and each focus on the display as a vessel for the awareness material. Crucially, neither considers the interaction between the individual and the artefact in producing SA.

In contrast to the views held by the Individualistic and Engineering perspectives the distributed cognition theory advocates System Ergonomics design principles to support SA. The concept of Distributed SA has significant implications for the design of complex system (Salmon et al., 2009b). Rather than seek to support identical awareness of shared situational elements, displays should support distinct but compatible SA requirements of different users and aid SA transactions among team members (Salmon et al., 2009c). Salmon et al. (2009b) suggested the provision of role-based interfaces, displays and tools that are designed around each user's distinct SA requirements. Displays and interfaces should present the SA information required by each user and should not contain information required by other roles and functions (Salmon et al., 2009b). A case study reported by Salmon et al. (2009b) suggested that this means providing customisable interfaces and role-based systems. An interesting example in this respect is the cockpit speed bug present in the analysis presented here. The speed bug is used by both pilots; however, the use of it is different. The PNF uses it to read and select the correct flap and slat settings while the PF uses the speed bug setting to guide the point at which they slow the speed of the aircraft and descends it for landing. Neither pilot needs to remember the speed of the aircraft and in this way the speed bug removes a significant part of the pilot's workload. The cockpit was not designed with distribution of work in mind, however, it is clear that the equipment has evolved over time (e.g. external speed bugs being used to indicate critical speeds is a case in point) to allow the pilots to offload certain mentally demanding tasks. If the pilots' SA were to be measured using individual SA methods; and include in this measure speed, the pilots would not be able to answer, for the awareness of speed is not held by either of them. Because the cockpit as a system has been constructed in a particular way remembering speed is no longer a requirement for SA. In calling for a systems approach to designing for SA this review calls for an explicit consideration of the role of each member of a team along with the artefacts in their environment and the consideration that SA ought to be distributed between them. Salmon et al. (2009b) argued that the utility of this approach lies in its output, in that it enables a description of the systems Distributed SA in terms of content, but also in terms of the relationships between them. Hence Salmon et al. (2009b) goes further than describing the pieces of information individuals need to know. Collaborative systems which allow information to be transmitted between agents and artefacts should be the focus of design. Achieving a good fit between a piece of equipment, such as a display, and the system in which it will be used receives less attention currently than the appearance of that display. It is recommended that designers should seek to establish a better balance.

Similarly, Walker et al. (2009b) reported a study which found poor SA in a command and control team involved in a battle group planning task. They reasoned that the poor level of SA was attributable to a number of external artefacts which enabled knowledge to be contained in the world. As such, it was not necessary for the team to remember specific elements of their planning which referred to for instance movement of forces as these were represented externally to them (Walker et al., 2009b). Woods and Sarter (2010) presented examples of technology which has created challenges for SA when they aimed to improve SA. By requiring the individual to keep track of yet more technologies the system is made increasingly more complex (Woods and Sarter, 2010). Instead, they suggest that design should be reframed in terms of how it can help people in their role as problem solvers (Woods and Sarter, 2010). This may mean, as exemplified above, that certain artefacts take over the responsibility for certain parts of a task (such as remembering speed) to allow the individual to focus on the more important task of flying the aircraft. As a consequence, if designers were asked to make a cockpit which enhances SA of the pilots, assuming no prior knowledge of cockpit design, then the three level approach would not design speed bugs into the cockpit given that an SA requirement analysis would not reveal a need to remember speed for either pilot. The Engineering approach, in contrast, would only design instruments but would not attune this to the different needs of the PN and PNF. This chapter takes the stance, however, that a System Ergonomics approach would reveal the need for external knowledge of speed and so design in speed bugs.

Stanton et al. (2010a) asserted that, as the idea of transactions suggest, information flows both ways. The process analysed here show how there is a constant flow of information around the system, from the PNF to the artefacts, from the artefacts to the PNF and from the PNF to the PF and so on. Thus, support for SA transactions need to be incorporated. One way to do so could be to map information together on displays (Salmon et al., 2008; Salmon et al., 2009b; Salmon et al., 2010). All of these suggestions indicate a considerable effort that need to be made by designers in understanding exactly what it is that users need to know, when they need to know it and what they need to know it for (Salmon et al., 2009b). This understanding needs to include what information should be presented, in what manner and to which elements of the overall work system (Salmon et al., 2009b).

As the above suggests the emphasis on SA as either contained entirely within the mind of an individual, resident entirely within the world, or as emergent, distributed, property gives rise to different views of how to support the development and maintenance of SA for teams. By taking a systems approach, however; as advocated by the distributed notion of SA, there is no need to neglect one perspective over another. Situating people within their environment and the context in which they operate in ensures that systems can be designed which foster the flow of information around the system, thereby supporting the transaction of SA and development of compatible SA. This gives rise to agile and dynamic teams within complex systems.

2.8 Conclusion

The intention of this chapter has been to apply the perspectives of the three main schools of thought on SA to analyse the process of descent and approach of an MD-80 as described by Hutchins (1995b). The analysis has shown how the Individualistic and Engineering schools emphasise distinct features of either the individual or the world, respectively, as fundamental to the development of SA. These, consequently, give rise to design of either cognitively oriented or technology focused devices. Despite providing useful contributions to the understanding of SA and to the design of SA relevant artefacts and interfaces, these approaches fall short of explaining the phenomenon completely. Here it is therefore proposed that the System Ergonomics school of thought, which combines the perspectives of the individual and the world, by considering the interaction between them, presents the most useful angle from which SA can be analysed and its emergence supported.

Whilst not without some merit, the Engineering school of thought has yet to deal with team SA. Literature pertaining to this perspective is therefore not considered in further detail in this thesis. The theoretical analysis provided in this chapter demands that an empirical test, of the ability of the Individualistic and the System Ergonomics schools of thoughts to reveal differences between teams' SA, is performed. Such a test will enable conclusions to be drawn in support of the arguments presented here. Building on the literature presented in this chapter, Chapter 3 therefore considers the measurement of team SA by investigating the unit of analysis which forms the basis for assessment for the Individualistic and System Ergonomics approaches. Comparisons of the most commonly used measures from these are considered and a test of each measure's ability to discern differences between two teams' SA was performed. Chapter 3 reports on this study and aims to contribute to the debate concerning the nature of team SA.

3 Is SA Shared or Distributed in Team Work?

3.1 Introduction

Chapter 2 has shown that there is still considerable debate concerning the nature of SA in teams and as yet there is neither consensus nor any single measure developed to assess the phenomenon (Patrick et al., 2006). Reviewing the extensive literature on SA in Chapter 2 identified a number of conceptual issues which differentiate perspectives on SA. In Chapter 2 it was illustrated how each of the three schools of thought provided differing explanations for how SA is manifest in the cockpit. It was argued that taking either a Individualistic or an Engineering approach to SA in teams ignores the interaction which takes place between human and non-human agents. The comprehensive analysis showed that the System Ergonomics approach offers a means by which the entire system (e.g. a team working within a complex environment, such as a cockpit) can be taken into account and shows how SA is distributed. Chapter 3 builds on these arguments by empirically testing the extent to which the Individualistic and System Ergonomics approaches reveal differences between team SA. Two models are considered here: the model of Shared SA which represents the Individualistic approach, while the more recent model of Distributed SA takes a System Ergonomics perspective.

In this chapter the two schools of thought (e.g. the Individualistic and the System Ergonomics) and their associated models are discussed in terms of how each explain team SA, what they consider to be the unit of analysis for team SA and how each approach measures team SA, followed by an empirical investigation with discussions and conclusions for team SA.

3.2 Explanations of SA

SA can be explained in terms of several aspects, two of which are considered here; as individual or as team SA. The Individualistic school of thought considers SA as being contained entirely within the mind of the agent (Stanton et al., 2010a). Endsley's (1995) three-level model has received the most attention of the contributions within this approach. As discussed in Chapter 2, this model presents SA as consisting of three separate levels: perception, comprehension and projection (Endsley, 1995). Endsley (1995) explained that by perceiving the available elements in the environment (Level 1) and understanding these (Level 2) the individual can make projections about the future (Level 3) and ultimately take actions in line with their predictions. This information processing approach to describing SA provides an intuitive definition of the concept (Banks and Millward, 2009).

In contrast, the System Ergonomics school considers SA as an emergent property arising from people's interaction with the world (Stanton et al., 2006a). Bubb (1988) defines System Ergonomics as:

> "the application of system technics on ergonomical problems" (p.233);

Both the term and its sentiment are in wider use within the Human Factors and Ergonomics community (Stanton, 2006; Klein et al., 1989; DeMeis, 1997). SA has been described as a systems phenomenon (Salmon et al., 2008; Salmon et al., 2009b). The approach argues that SA is distributed cognition, where the mind is situated in an interdependent relationship with the world (Stanton et al., 2010a). Stanton et al. (2006a) therefore established a theory of Distributed SA. The System Ergonomics approach does not dismiss or ignore the individual's role in the development of SA; however, the distributed model of SA considers that the individual is simply one part of the system (Stanton et al., 2006a). As described fully in Chapter 2, the individual holds genotype schemata which are activated by the task which is being performed (Stanton et al., 2009c; Stanton et al., 2009d; Salmon et al., 2009a; Salmon et al., 2009c). Through task performance the phenotype schemata are created by the interaction between people, the world and artefacts (Salmon et al., 2009a). In this approach it is assumed that SA does not reside within the individual alone but within the system. In a similar way, Bedny and Meister (1999) argued that individuals are so closely coupled to their environments that they cannot be analysed in isolation from it; as such, people and artefacts form a "joint cognitive system" (Hollnagel, 2001). This is echoed by Gorman et al. (2006) who considered SA to be an interaction-based phenomenon.

Salmon et al. (2008) argued that cognitive processes emerge from, and are distributed throughout, the system. It is the interactions between people and technology which enables distributed cognition (Salmon et al., 2008; Salmon et al., 2009b). Patrick and Morgan (2010) highlighted that the individual needs to continuously extract and make sense of its environment and argued that:

> "the important point is that the relevant awareness and comprehension of something in the environment is determined by the goals of the system that can be decomposed both between and within people and artefacts" (p.5).

Smith and Hancock (1995) are drawing on Neisser's (1976) Perceptual Cycle Model when considering SA. Accordingly, they argued that information and action flow incessantly around the cycle, as quoted in Chapter 2 (p.13). In this way the world informs the individual whose knowledge directs their activity and which in turn impacts on the world (Niesser, 1976).

Endsley's (1995) model provides an integrated and coherent definition of the phenomenon of the individual (Wickens, 2008). The definition is often favoured in the literature as it is easily operationalised by the three discrete levels of SA (Banks and Millward, 2009; Alberts and Hayes, 2006; Ackerman, 1998). Within the Individualistic school of thought and within the frames of Endsley's model, team SA is understood as Shared SA where team members share SA requirements for a task. Nofi (2000) stated that Shared SA implies that all team members understand a given situation in the same way. A benefit of this approach is that if the team essentially is 'one person' support can be aimed at the team as a whole through the use of shared interfaces and training. Yet Salas et al. (1995) argued, as do others, that team SA is more than the sum of its parts (Masys, 2005; Salmon et al. 2009c; Salmon et al., 2009b). Therefore, simply adding individual SA together to provide a measure of team SA is not satisfactory (Gorman et al., 2006).

In contrast to the additive approach, Stanton et al. (2006b) advocated the view that team members possess unique but compatible parts of system awareness, rather than share SA. They argue that compatible SA is the glue that holds the distributed system together (Stanton et al., 2006a; Stanton et al., 2009c; Stanton et al., 2009d; Salmon et al., 2009a). Individual team members enhance and update each other's awareness through SA relevant transactions (Salmon et al., 2009a). These transactions may be interpreted in light of their specific tasks and goals (Salmon et al., 2008).

In Chapter 2, the definition of Distributed SA presented by Stanton et al. (2006a) was given as:

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

This definition is considerably more difficult to operationalise than that given by Endsley (1995) as what is 'activated knowledge' may include cognitive and behavioural processes across the system. What constitutes 'knowledge' must, for instance, be separated out from mere data and information; however, such analysis have merit as it enables analyses of what may have been 'missing' in situations where there has been a breakdown in team performance, such as in fratricide incidents (Rafferty et al., 2010).

Salmon et al. (2008) clarified the definition of Distributed SA by explaining that information held by the system becomes active at different points in conjunction with the goals and tasks being performed and their associated constraints. As such, individuals may have different SA for the same situation, depending on their team role and tasks (Salmon et al., 2008). It is therefore important to define the boundaries of the team or the system in conjunction with the individual parts making it up. This requires effortful analysis but provides a fair reflection of the nature of team dynamics and the complex environments they operate in.

Communication, as an SA transaction, connects and maintains the different parts of the distributed system. The model of team SA as distributed therefore views the system as a whole:

> "by consideration of the information held by the artefacts and people and the way in which they interact" (Stanton et al., 2010a, p.34).

The differing explanations of the phenomenon of team SA, as outlined above, take different units of analysis as points of measurement.

3.3 Unit of analysis

The Individualistic approach emphasises cognitive capabilities of the individual that are necessary and sufficient to achieve SA. Sarter and Woods (1991) considered SA as a variety of cognitive processing activities which are critical to agile performance. A mental theory of the world, developed by the individual, supports an understanding of how parts fit together and of how future states of the world can be foreseen (Banbury et al., 2004). Artman (2000) emphasised the individual as an active intermediary in developing SA and sees it as an:

> "active construction of a situation model" (p.1113).

The Individualistic approach therefore takes the individual as the unit of analysis for SA. In contrast, it is the system which is the unit of analysis in the Distributed SA framework and the System Ergonomics approach (Salmon et al., 2009b). Klir (1972) defined a system as:

> "an arrangement of certain components so interrelated as to form a whole" (p.1)

While von Bertalanffy (1950) stated in explaining the tenets of the General Systems Theory that:

> "living systems are open systems, maintaining themselves in exchange of materials with [their] environment" (p. 23).

The model of Distributed SA is therefore founded 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" (Salmon et al., 2008, p.369).

This is similar to Hollnagel's (2001) argument that team behaviour should be analysed at a macro level, e.g. by taking the environment and context of the team into account (Stanton et al., 2001a). The two theoretical approaches described above suggest that there is still disagreement as to how team SA is best understood, either the sum of individuals or the team interaction as a whole. The different entities under analysis in the Individualistic and System Ergonomics approaches to SA informed the development of diverse measurement techniques which are considered in the following.

3.4 Measurement of SA

The most popular measure within the Individualistic school of thought is the Situation Awareness Global Assessment Technique (SAGAT) which is developed from Endsley's three-level model (Endsley et al., 1998). SAGAT is presented as an objective measure of SA in individuals, although Annett (2002b) argued that all knowledge is based on subjective experience, casting some doubt on whether complete objectivity in self-reporting measures is possible.

Endsley et al. (1998) asserted that measures of SA provide an index of the ability of individuals to acquire and integrate information from the environment. Measurement within the Individualistic approach therefore seeks to determine, either through objective or subjective measurement techniques, the extent of this ability in an individual. The objectivity is claimed by the freeze-probe technique which involves the simulation of any operation, such as air traffic control, being frozen at a random point in time and specific questions about the situation (as it was before the freeze) are presented (Endsley et al., 1998). A SAGAT score is calculated for each participant after the simulation (Stanton et al., 2005). Endsley et al. (1998) argued that the main advantage of SAGAT is its provision of an index across the three levels of SA. An obvious disadvantage is that the measure requires freezes to take place, disrupting natural task performance (Endsley et al., 1998; Endsley et al., 2000). Another criticism of the measure is that it is heavily reliant on memory (Salmon et al., 2009c). Despite its origin as an individual measure of SA it has also been applied to assess team SA. Although heavily criticised when used to provide a team measure (Salas et al., 1995; Masys, 2005; Salmon et al., 2008; Salmon et al., 2009b; Stanton et al., 2009a; Stanton et al., 2006a; Stanton et al., 2010a; Patrick and Morgan, 2010), the SAGAT scores of the individuals in the team are averaged to provide an overall score for team SA (Salas et al., 1995; Masys, 2005; Salmon et al., 2008; Stanton et al., 2009a).

The Situation Awareness Rating Technique (SART) is also a popular measure within the Individualistic approach (Taylor, 1990). SART provides an assessment of SA based on operators' own subjective opinions (Taylor, 1990). 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 demand on their resources, the supply of resources available to them and their understanding of the situation (Endsley et al., 1998). The scales are combined to provide an overall measure of SA (Endsley et al., 1998).

Given that Distributed SA considers the joint cognitive system as a whole it is clear that measurement of SA within this theoretical framework must take a broader systems theoretical view. Kirlik and Strauss (2006) argued that a:

> "comprehensive approach to SA modelling and measurement requires techniques capable of representing and decomposing both the technological and psychological contributions to SA" (p.464).

The aim here is to consider the interaction between individuals and their environment to achieve a holistic picture of the SA contained in a system (Stanton et al., 2010a). Kirlik and Strauss (2006) went on to state that:

> "modelling SA as distributed is important in an engineering sense because only techniques capable of representing the external contributors to SA are capable of analysing and predicting how technology design influences on SA" (p.464).

Social Network Analysis (SNA) and Propositional Networks (PN) have been applied as a way of describing Distributed SA as these are able to reveal the information which constitutes a systems knowledge, the relationships between the different pieces of information and the ways in which each component in the system utilises it (e.g. Stanton et al, 2008; Salmon et al., 2008; Houghton et al., 2006). These reflect the 'object-relation-subject' patterns within the Critical Decision Method (CDM; Klein and Armstrong, 2005) and give an insight into inherent knowledge structures of the system and the way in which these may be activated (Salmon et al., 2009b). Distributed SA is therefore represented in pieces of information and the relationship between them as demonstrated in Chapter 2 (Salmon et al., 2009c; Stanton et al., 2010a). A PN can reflect the entire systems SA by showing all the information contained within it, as well as identifying individuals or artefacts within the system in detail. The latter approach enables a consideration of compatible SA.

Theoretical deliberation of the phenomenon of SA has considered whether it is best understood as a product or a process (Sarter and Woods, 1991; Endsley, 1995; Banbury et al., 2004; Stanton and Young, 1999b). As all four measures (i.e. SAGAT, SART, SNA and PN) from both the Individualistic and the System Ergonomics schools of thought consider the overall SA attained within each of the conditions at the end of task performance, all can be understood as 'product' measures. However, the measures of Distributed SA have the potential to consider both the product of SA and the process of achieving it by considering the emergence of SA through interactions within a system over time.

It is clear from the discussion above that the two schools of thought, despite seeking to explain the same phenomenon, offers different conceptions of the nature of SA. Consequently, if the Individualistic approach provides the most appropriate theory of team SA then SAGAT and SART would be the more sensitive measures, and conversely, if the System Ergonomics approach offers the most appropriate theory then PNs and SNA would prove the more insightful measure. The following hypotheses were therefore tested to ascertain which approach had the sensitivity required to distinguish between two different teams and explain these differences:

- Hypothesis 1: The measures derived from the Individualistic tradition of SA – SAGAT and SART – will reveal differences between the two conditions, if SA is shared between team members;

- Hypothesis 2: The measures derived from the System Ergonomics tradition of SA – SNA and PNs – will reveal differences between the two conditions, if SA is distributed between team members.

3.5 Method

3.5.1 Participants

A sample of 34 participants was drawn from the University of Southampton's postgraduate population. The participants were randomly divided into two groups, one with a Hierarchical organisational structure and one with an All-connected organisational structure, with 17 participants in each condition. Both conditions had an identical mean age of 28 (S.D. = 5.52). In the Hierarchical condition there were 15 males and 2 females, while in the All-connected condition there were 12 males and 5 females. Though there are fewer female participants than would be expected from the general student population the purpose of this case study was to discover differences revealed by the SA measures and as such the gender bias was not expected to impact on the findings. Furthermore, students were selected as participants as a result of research which has shown that there is no difference between using novices, such as students, and experts for simple task measures such as those considered here (Walker et al., 2010). Ethical permission for the experiment was requested and granted by the University of Southampton.

3.5.2 Design

The study was a between-subjects experimental design. The between variable was organisation structure; Hierarchical and All-connected and participants were randomly assigned into either of these. The Hierarchical condition had three layers, one coordinating leader, four team leaders in the middle and three team members reporting to each team leader as illustrated in Figure 3.1.

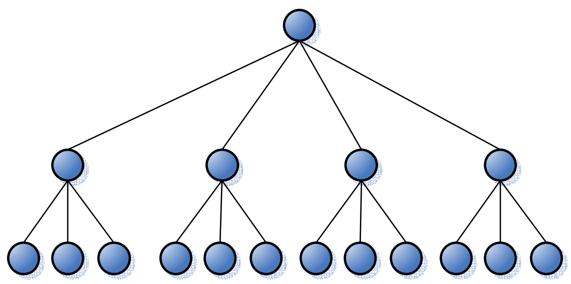


Figure 3.1. Hierarchical organisational structure

The All-connected organisational structure allowed all team members to interact with any other team member, as seen in Figure 3.2. Information had the potential to flow freely between team members and the group was self-managed.

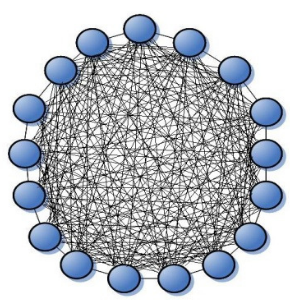


Figure 3.2. All-connected organisational structure

The use of different organisational structures to design different experimental groups has also been reported elsewhere (Walker et al., 2009a; Clegg, 2000). The dependent variables were SA, time and task performance.

3.5.3 Equipment

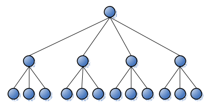
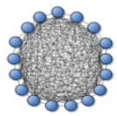
The study utilised the ELICIT software tool which allows for an organisation of participants in the two conditions while they perform an intelligence analysis task (Ruddy, 2007). The ELICIT Log Analyzer (CCRP, 2009) was used to extract performance data. The experiment software organises the team interaction according to the organisational structure they are divided into. A computer room was set up which provided a computer, keyboard, mouse, desk and chair, for each of the participants and the study leader. In addition headphones were supplied for the participants, allowing them to listen to video instructions describing the software interface. Paper copies of the questionnaires were administrated while pens and sheets of paper were made available for participants to make notes during the experiment.

3.5.4 Task

The participants were instructed to use information elements supplied during the experiment to establish the 'who', 'what', 'where' and 'when' of an adverse attack. Once the correct solution was supplied by either team in the ELICIT experiment software the experiment ended.

In the Hierarchical condition the participants were divided into one of the three team functions, cross-team coordinator, team leader or team member. They were further grouped by topic to identify either who, what, where or when of the adversary attack. In the self-managed All-connected condition all team members contributed equally to the identification of who, what, where and when of the attack. Both groups were required to utilise the organisational structure they were organised into to successfully complete the team task collaboratively. This was done by compiling information, posting it on relevant group web pages and sharing it with relevant team members (Ruddy, 2007). Importantly, in the Hierarchical condition access to information was constrained by the team function to which a participant was allocated. In this way only team members in the "who" group could access information related to "who" was involved with the attack, such as information shared with them by other team members, information sent from the experiment software (so called 'official' information) and information posted on the who information related website. The cross-team coordinator had access to information on all web pages and could communicate with anyone. The All-connected condition had no such constraints and each team member could share information with anyone else as well as utilise information posted on any web page. See Table 3.1 for an overview of each condition's specific access to information. The single task presents a limitation for the experiment design.

Table 3.1. Access to information

Condition	Availability of information
	Teams structures into separate groups of 'Who' or 'What' or 'When' or 'Where' information.
	All participants have access to 'Who' and 'What' and 'When' and 'Where' information.

3.5.5 Procedure

The study used the procedure set out in Ruddy (2007), comprising the following steps:

- Participants were recruited and randomly assigned to either Hierarchical or All-connected conditions;
- Participants welcomed and the experiments aims described briefly;
- A video was shown to demonstrate how the experiment software should be used;
- In the Hierarchical condition participants were at this point randomly assigned into one of four groups and team roles (i.e. either ‘who’, ‘what’, ‘when’ or ‘where’);
- Participants randomly assigned to the self-managed All-connected group had access to all information;
- Familiarisation game. No talking allowed during or after the game. Technical help given to any participant who has questions about the experiment interfaces;
- A short break was given but no talking was allowed;
- The experimental game was started. All interaction occurred via textual means using the ELICIT experiment software interface;
- Administration of experimental questionnaires;
- Debriefing of participants.

3.5.6 Data reduction and analysis

A SAGAT questionnaire was administered and a score calculated (Endsley, 2000). The SAGAT probes were developed from the information elements provided in the game and categorised into the three levels of SA as described by Endsley’s (1995) model. The highest possible score was 21. Individual SAGAT scores were calculated separately for each team member and a median for the team was obtained. In line with the literature described above, the SAGAT score provides an indication of Shared SA in the two conditions. The three levels of SA as measured by SAGAT were investigated using a histogram to compare the Hierarchical and All-connected conditions. In addition a SART questionnaire was administered and a median score was calculated for the team (Stanton et al., 2005; Annett, 2005). To compare difference in mean rank of SAGAT and SART scores between the two groups a non-parametric Mann-Whitney U test was performed for each score.

Distributed SA was measured using the CDM; which were analysed to produce PNs (Salmon et al., 2009b; Klein, 2000; Klein and Armstrong, 2005). Walker et al. (2010) described the process of data reduction and creation of PNs from the outputs of CDM transcripts, which was followed here; firstly a word frequency list was established from the CDM transcripts, and secondly, words with an insufficient frequency were discarded. This enables words which form the PNs to focus on the group contributions, not individuals (Walker et al., 2010). Walker et al. (2010) explained that by plotting a word frequency list in a graph,

> "the word frequency curve approximates to a form of Scree plot" (p.477).

Drawing a line to where the curve flattens out provided a cut-off point for words of an individual nature, leaving the group relevant words with the higher frequencies. An inter-rater reliability test was performed which achieved 80% agreement.

SNA was used to examine the structure of communications and reveal patterns that emerged in each condition, as has been done elsewhere (Walker et al., 2006; Walker et al., 2009a). A social network can be created by plotting who is communicating with whom, or what concepts are associated with which other concepts, in a matrix. The matrix denotes the presence, direction and frequency of a communication link (for instance, that player 1 communicates with player 5 a total of 50 times). In order to describe the PNs in a quantitative manner, SNA of the PNs' diameter, density, Bavelas-Leavitt (B-L) centrality and sociometric status, number of nodes and number of links between nodes was performed. This was done by establishing a matrix of association showing which words, or nodes, that were connected to any other.

Diameter measures the largest number of agents which must be traversed in order to travel from one node [or agent] to another (Endsley, 1999b; Redden and Blackwell, 2001). As such the diameter of a network gives an insight into how 'big' it is. Walker et al. (2009d) stated that:

> "the maximum value for density is 1, indicating that all nodes are connected to each other" (p.85-6).

The density of a network is therefore the proportion of all the ties observed in the network and gives insight into the speed at which information can be diffused (Walker et al., 2009d). The B-L Centrality statistic gives a centrality value for each node in the network by calculating:

> ”the most central position in a pattern [which] is the position closest to all other positions” (Leavitt (1951) cited in Walker et al., 2009d, p.18).

Walker et al. (2009d) hypothesised that Hierarchical organisational structures would generally possess fewer highly central agents compared with All-connected organisational structures.

Sociometric status pertains to the contribution made by agents in the network. The higher the sociometric status an agent is given the higher the contribution this agent makes in terms of the flow of communication within the network (Houghton et al., 2006). Sociometric status was measured to identify the information concept most frequently occurring in either PN, while a simple count was made of the number of nodes and the links existing between them.

The structure of communication was thus examined and patterns of qualitative differences were quantitatively investigated (Walker et al., 2009a). See Salmon et al. (2009b) for a further discussion of PNs as an analytical and representational tool for Distributed SA and Walker et al., (2006; 2009a) for further discussion of the use of SNA.

In addition, performance was measured to investigate differences arising from the organisational constraints placed on the teams. Performance was measured in terms of sharing behaviours, how quickly either team completed the task and whether they correctly identified the solution. It was expected that there would be a difference in the time taken to complete the task, while it was expected that both conditions would complete the task successfully. The following hypothesis was tested:

- Hypothesis 3: The performance of the two conditions as measured by ELICIT will reveal differences between them in terms of time to complete, correct identification and sharing behaviours.

3.6 Results

The results of the measures related to SAGAT, SART, SNA and PNs for the two teams are briefly presented.

3.6.1 SAGAT

A median score of 12 was obtained for the Hierarchical condition while a median of 13 was obtained for the All-connected condition, neither team’s SAGAT score was more than just over half of the maximum score of 21, see Figure 3.3. There were no statistically significant differences between the Hierarchical and All-connected conditions on the overall SAGAT scale ($U = 0.559$, P = N.S.). Participants in both conditions therefore reported the same level of objective SA.

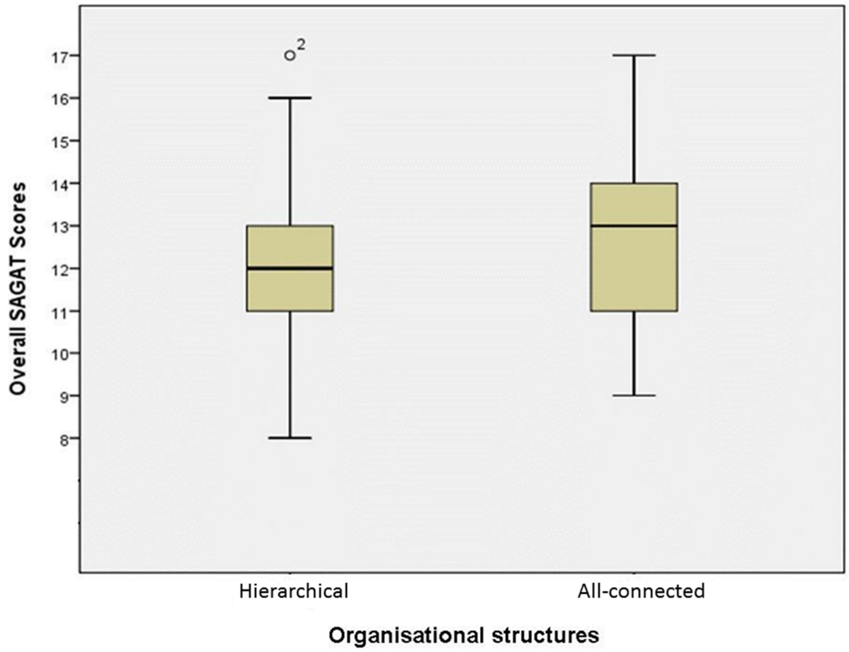


Figure 3.3. SAGAT scores for the two organisational structures

The SAGAT scores associated with the three levels of SA described by Endsley (1995) were compared for the two conditions, illustrated in Figure 3.4.

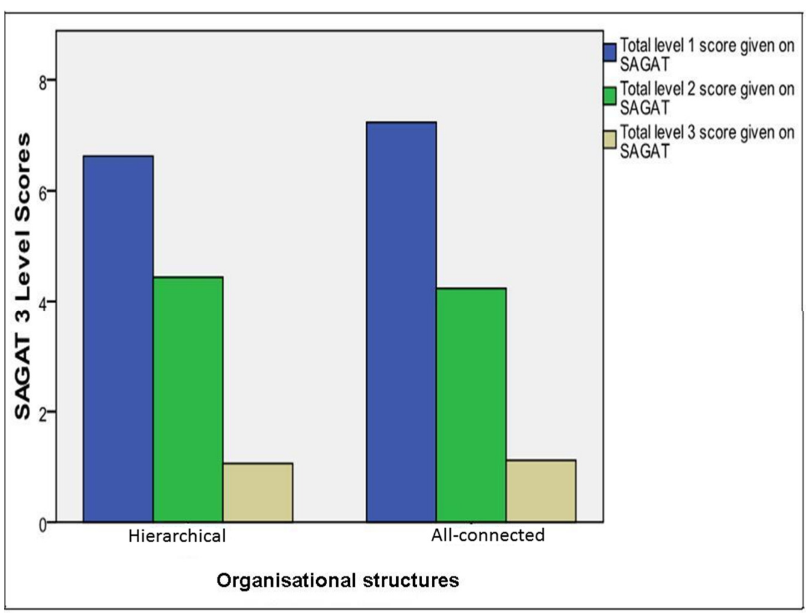


Figure 3.4. SAGAT score by the three SA levels for both organisational structures

Mann-Whitney U tests were performed for each of the three levels of SA to determine whether the medians obtained for each level were equal for the two conditions. No statistically significant differences were found for level 1 (U = 85.5, P= N.S.), level 2 (U = 119.5, P = N.S.) or level 3 (U= 128.00, P= N.S.) when compared between Hierarchical and All-connected conditions.

3.6.2 SART

The median SART score achieved for the Hierarchical and All-connected conditions was 4 and 5 respectively. No statistically significant differences were found for the Mann-Whitney rank sum test on the overall SART scale (U = 0.786, P = N.S.). Participants therefore report the same relatively low level of subjective SA in both conditions. Figure 3.5 show the spread of SART scores.

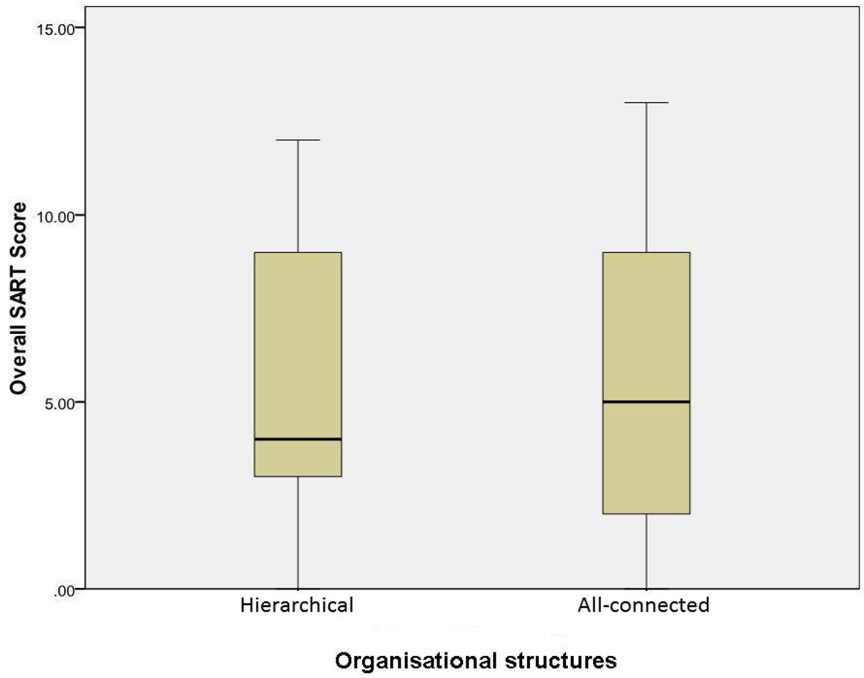


Figure 3.5. Spread of SART scores

The median achieved by the two team conditions on each of SART's three dimensions were compared, see Figure 3.6. No statistically significant differences were found between Hierarchy and All-connected conditions when considering the test statistics of the Mann-Whitney rank sum test on either of the SART dimensions: demand (U=142.00, P=N.S.), understanding (U=139.50, P=N.S.) and supply (U=140.00, P=N.S.).

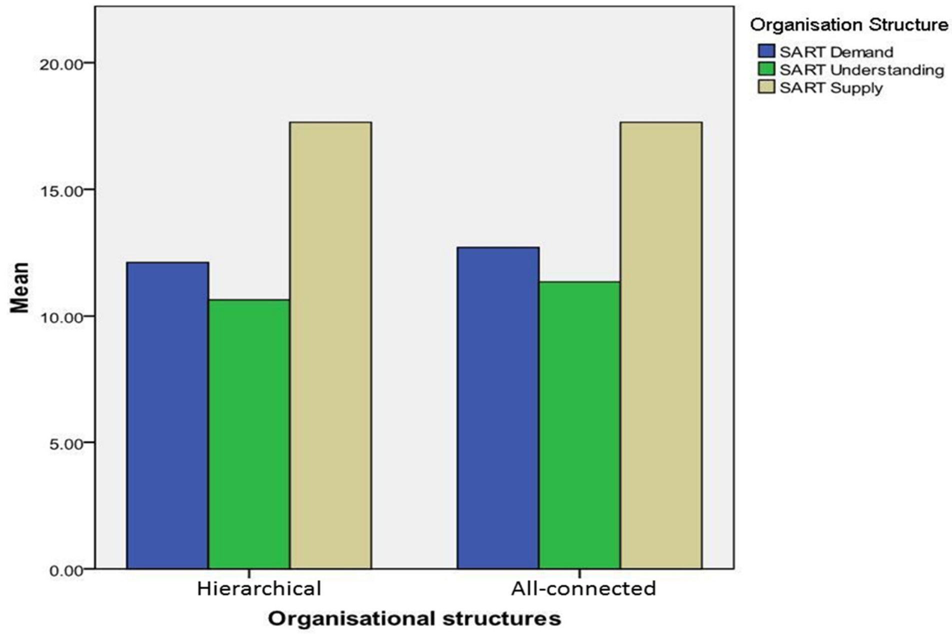


Figure 3.6. SART score by the three SA dimensions for both organisational structures

The outcomes of the two measures were examined using the Mann-Whitney two-sample rank-sum test. There were no statistically significant differences between the overall SAGAT (U = 120, P = N.S.) and SART (U = 129, P = N.S.) scores. Similarities between SAGAT and SART were investigated further by subjecting the three SA levels measured by SAGAT and the three main dimensions of SART (demand, understanding and supply) to Spearman's test of correlation. No statistically significant correlation was found between any of the three SAGAT levels and the SART dimensions (P = N.S.). Hence no difference was found between the two measures for either condition.

The findings above did not reveal any statistically significant differences between the Hierarchical and All-connected conditions in terms of the quantitative measures of SA derived from the Individualistic school of thought. No support was therefore found for hypothesis 1. In the following section the results with regards to hypothesis 2 are presented.

3.6.3 Propositional networks

Frequency counts of words extracted from the CDM (Klein, 2000; Klein and Armstrong, 2005) transcripts were performed. Cut-off points were identified for words which were to be included in the PNs as nodes (only words appearing frequently are of interest to this team level analysis). For the Hierarchical condition the cut-off point was 4, hence no concepts mentioned fewer than 4 times were included, as illustrated in Figure 3.7

(Salmon et al., 2009b). For the All-connected condition the cut-off point was 5 individual citations (see Figure 3.8).

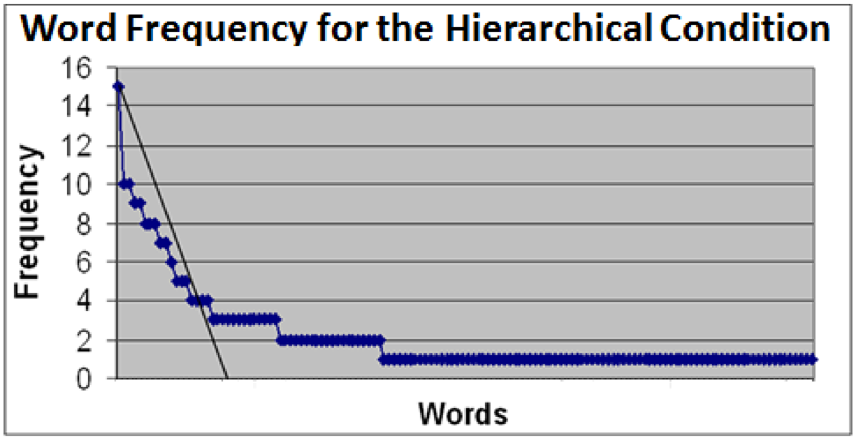


Figure 3.7. Frequency of words for the Hierarchical organisational structure

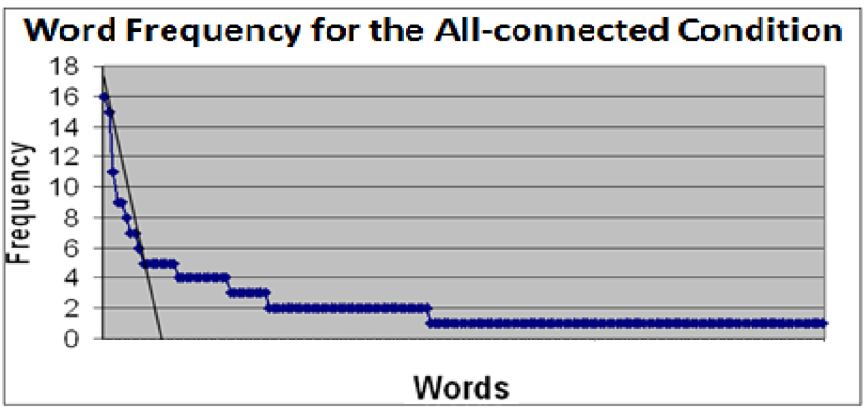


Figure 3.8. Frequency of words for the All-connected organisational structure

Figure 3.9 depicts the PN created from the subject-relation-object patterns revealed in the CDM responses for the Hierarchical condition; Figure 3.10 displays these results for the All-connected condition.

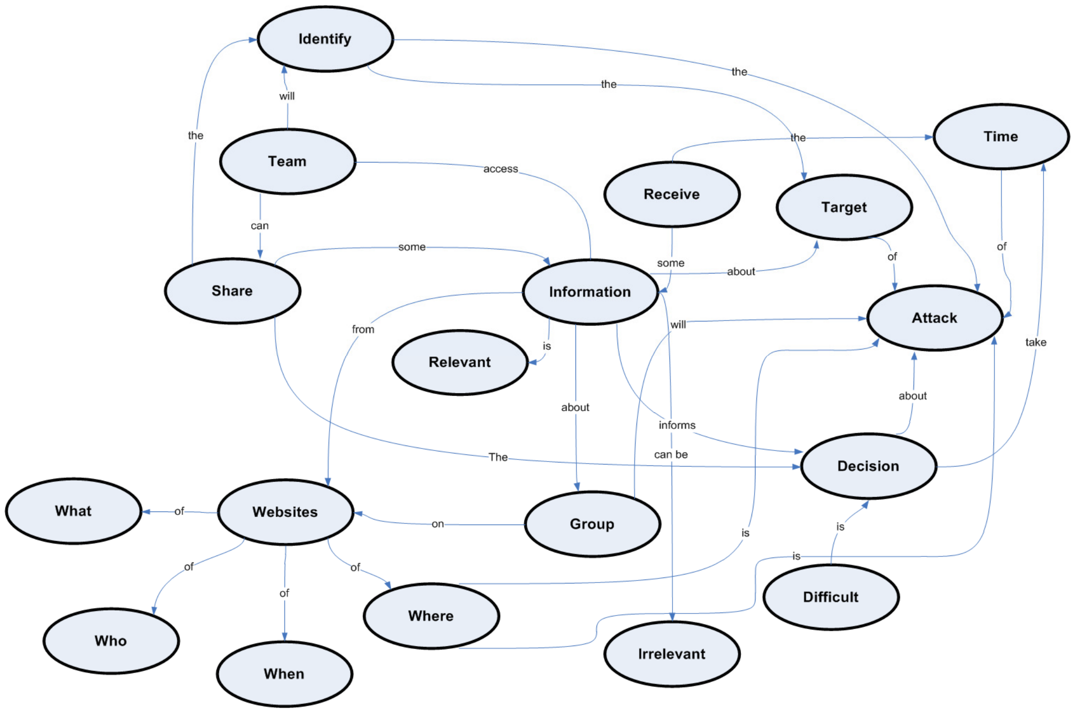


Figure 3.9. Propositional Network for the Hierarchical organisational structure

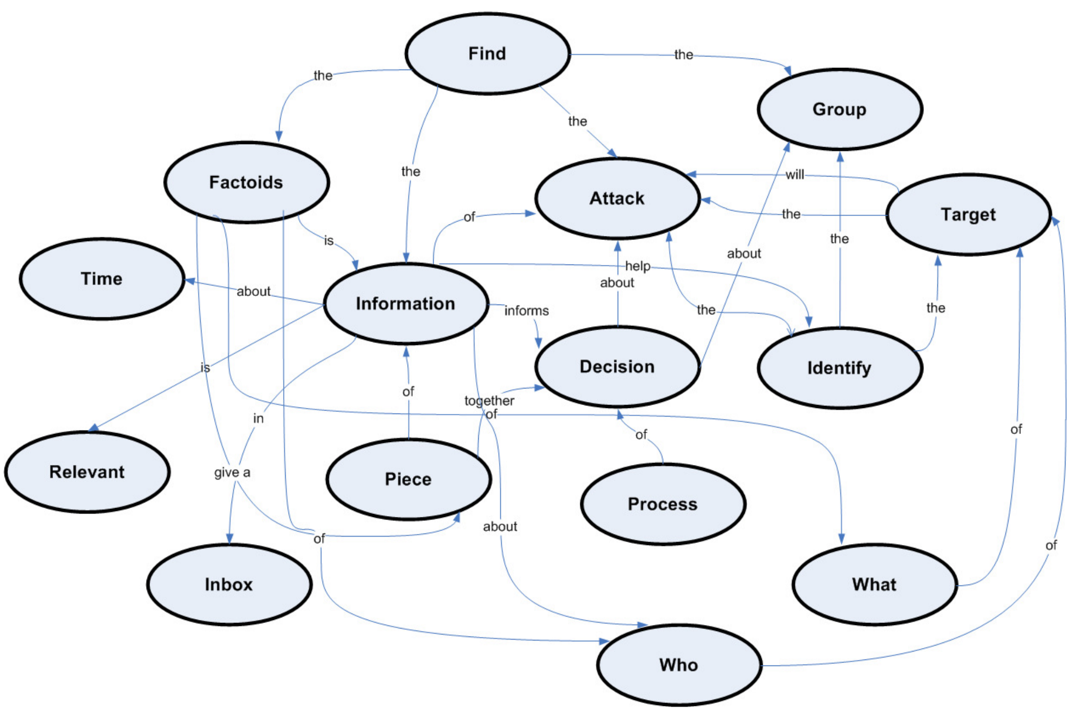


Figure 3.10. Propositional Network for the All-connected organisational structure

The PNs show that although they contain many of the same conceptual elements there are a number of concepts that are exclusive to one condition. For instance, “receive” exists only in the Hierarchical condition, while “process” is unique to the All-connected condition. The relationships between the concepts in any of the PNs are also qualitatively different, which reflect that the information available to the team was utilised in different ways. For instance, in the Hierarchical condition the information element “information” is directly connected to “attack” but only indirectly connected to “target” (through “attack”). This is reversed in the All-connected condition.

3.6.4 Social network analysis

Applying network analysis to the pattern of communication enables a quantitative probe of the qualitative findings given above. Table 3.2 shows the SNA statistics obtained for the PNs diameter, number of nodes, links between nodes, density, centrality and sociometric status.

Table 3.2. SNA statistics for Hierarchical PN and All-connected PN

	Hierarchical	All-connected	% difference
Diameter	2.0	2.0	0.00%
Number of nodes	15	18	16.67%
Links between nodes	26	28	7.15%
Density	0.53	0.41	22.65%
Centrality (mean)	8.91	8.33	6.51%
Sociometric status (mean)	3.63	4.44	18.25%

As can be seen from Table 3.2. above, the Hierarchical PN was denser than the All-connected PN. In both structures “Attack” was the node with highest sociometric status, although the higher mean for sociometric status for the All-connected PN indicated that “Attack” had greater connectivity in this condition. This means that the nodes which were connected to the “Attack” node referred to it more frequently in the All-connected PN than in the Hierarchical PN.

The Hierarchical and All-connected PNs have 10 nodes in common; however, each condition had a number of additional nodes which were not shared. In the All-connected PN there were 8 additional nodes: team, share, receive, difficult, irrelevant, websites, when and where. These additional nodes refer to three themes: team work, issues with information and source of information. The Hierarchical PN had 5 additional nodes: inbox, piece, factoid, find and process. These refer to searching for information. On all other metrics there are only small differences.

The findings from the PNs and SNA analyses revealed qualitative and quantitative differences between the two conditions. Support was therefore found for Hypothesis 2.

3.6.5 Performance

The All-connected condition achieved task completion in 2292 seconds which was marginally faster than the Hierarchical condition, which completed in 2440 seconds (i.e. the All-connected condition was 2 min 28 sec faster than the Hierarchical condition).

Both conditions correctly identified the solution in the experimental trial. In the Hierarchical condition it was only the Commander who could make an identification attempt and this participant correctly identified the solution. In the All-connected condition there were 4 identification attempts, of which 3 were successful.

Three types of sharing behaviours were measured; direct shares between team members: posting on web sites and pulling information from these web sites.

There were greater instances of sharing in the Hierarchical condition (326) than in the All-connected condition (119). Similarly, there were a greater number of web-site posts in the Hierarchical condition (154) than in the All-connected condition (131). However, there were greater instances of pull, i.e. extracting information, in the All-connected condition (747) than in the Hierarchical condition (167). See Table 3.3.

Table 3.3. Sharing behaviours

	Hierarchical	All Connections
Share	326	119
Post	154	131
Pull	167	747

These findings therefore reveal a small difference between the two conditions, specifically with regards to the patterns of sharing behaviours the conditions displayed. Hypothesis 3 is therefore supported. The findings are summarised in Table 3.4.

Table 3.4: Summary of Main Findings

	SAGAT	SART	PN	SNA	Outcome measures	Performance
Hierarchy	(Median) 12	(Median) 4	5 nodes not shared with All-connected condition.	15 nodes	Greater instances of direct sharing	Slower getting to solution
All-connected	(Median) 13	(Median) 5	8 nodes not shared with Hierarchical condition	18 nodes	Greater instances of information pull	Quicker getting to solution
Difference	No statistically significant difference found	No statistically significant difference found	Qualitative differences found between the PNs.	Hierarchy found to be denser than the All-connected PN	Difference found between conditions on share and pull behaviours	Differences between the SA exhibited by either team revealed by the PN and SNA results

3.7 Discussion

This study aimed to contribute to the on-going debate about appropriate theory and measures to assess team SA. By contrasting two approaches to SA the discrepancy between them in terms of their explanation of what SA is, the unit which are subjected to analysis and how the phenomenon are measured has been highlighted. By applying quantitative and qualitative measures, which have been developed within these approaches, this incongruity was further emphasised.

Within the Individualistic school of thought Shared SA is understood as shared SA requirements for team members (Endsley and Robertson, 2000; Endsley, 1995; Nofi, 2000). A difference was therefore expected to be revealed between the Hierarchical and All-connected conditions when analysing SA as Shared SA, as measured by SAGAT and SART. Specifically, it was expected that the All-connected organisation, in which all team members share the same team role and task responsibility, would obtain a higher SAGAT score than the Hierarchical condition. However, the findings for each Shared SA measure did not reveal any difference between the two conditions. No support was therefore found for hypothesis 1.

SAGAT and SART aim to reveal the product of SA as the individual has achieved it in task performance. In effect these measures therefore consider each individual in isolation by estimating how much of the overall situation they were aware of at the time of measurement. These estimates are then added together to give an overall team score. Gorman et al. (2006) expressed concern that simply adding individual SA together to give team SA scores is unsatisfactory. The findings presented here emphasise that such concerns remain relevant. Stanton et al. (2010a) argued that using individual SA measures to interpret team SA does not take into account the wider environment of the individuals which is utilised to aid task performance in the most efficient way, e.g. artefacts and other team members. While SAGAT and SART have been proven (Banbury et al., 2004; Endsley et al., 1998) to give valuable insight into individual SA the findings presented here indicate that these may be less sensitive when applied to assess team SA.

The System Ergonomics school of thought, in contrast to the notion of team SA as being shared, argues that SA is an emergent property of collaborative systems. The qualitative findings in the PNs reflect collaborative systems in the differing patterns of interactions which emerged. 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 SA holds the distributed system together. They further argued that Distributed SA is activated knowledge which is utilised for a particular task within the system. The PNs showed the relevant information contained within the two conditions and the relational links between them. These links showed how the information elements were utilised within the teams. Both PNs therefore exhibited Distributed SA. The PNs for the two conditions showed that the two teams utilised their organisational structure in different ways to coordinate their efforts for successful task completion. The PNs further showed that although they contain many of the same conceptual elements there were a number of concepts that were exclusive to only one organisational structure, revealing qualitative differences between them.

The SNA data found that the Hierarchical PN was denser than the All-connected PN. In contrast the All-connected PN had a higher mean sociometric status than the Hierarchical PN. The findings of the PNs and the SNA reveal qualitative (i.e. differences in the concepts represented by the nodes) and quantitative (i.e. data shown in Table 3.2) differences between the two conditions. The performance measures which revealed differences between the two conditions' sharing behaviours support the findings from the PNs and SNA. Support was therefore, in part, found for hypothesis 3.

The ability of the measures of Distributed SA to reveal a difference between the two conditions provided support for hypothesis 2. The findings reported here therefore lend support to the notion of Distributed SA, expressed by Salmon et al. (2008), that understanding behaviour in complex systems requires study beyond the individual components of a system to consider also interactions between them. Team behaviour should be analysed at a macro level (Hollnagel, 1993). The comparison of the two theoretical approaches to SA - Shared and Distributed SA - therefore showed that Distributed SA was a sensitive measure of team SA and this was verified by the subtle differences in task performance.

3.8 Conclusion

The study presented in this chapter has compared the Individualistic and System Ergonomics approaches to SA and also measured team SA within these frameworks. The findings demonstrated differences in terms of how they explain the phenomenon, the level of analysis and methods for assessment. The unit of analysis in the Individualistic approach is the individual, whereas the entire system is analysed in the System Ergonomics approach. In the Individualistic approach the SA captured is considered a product, whilst it is considered as a process arising from interaction in the System Ergonomics approach. Explaining SA as either a cognitive construct residing in the mind of an individual, or as a systems phenomenon that emerges through interaction between individuals and artefacts within the system, naturally leads to different measurement techniques. No significant statistical differences were found between the two different team structures when considering the scores obtained for SAGAT and SART (measures developed within the Individualistic school of thought to assess individual SA). Both qualitative and quantitative differences were found, however, when applying SNA and PNs (measures developed within the System Ergonomics approach to assess team SA). These findings were also supported by differences found in the performance of the two conditions, specifically different patterns of sharing and pulling behaviours. As such, the measures derived from the Individualistic school of thought did not reveal differences between the two teams whilst the measures derived from the System Ergonomics school of thought were able to reveal small differences between them.

The results presented here emphasised the need to clarify the nature of team SA and the associated measures which are appropriate to assess this particular phenomenon. These findings support the arguments presented in Chapter 2 which highlight the need to take system interactions into account in order to fully explain team SA. As such, the remaining work presented in this thesis will concentrate on expanding and validating the model of SA presented in the Distributed SA framework. Chapter 4 focuses on three measures of Distributed SA addressing the question of when each measure should be applied to assess the SA phenomenon in teams.

4 When Can Distributed SA be Assessed: Before, During or After Command and Control Activity?

4.1 Introduction

The findings presented in Chapter 2 and Chapter 3 highlighted the need for further investigations to be made to identify the best measurement of Distributed SA. This chapter considers measurement by presenting a review of three measures of Distributed SA and considering when these should be applied to assess the phenomenon.

North Atlantic Treaty Organization (NATO, 2006) describe the battle space in which C2 must operate in as a ‘problem space’ which is characterised by three dimensions; rate of change, strength of information position and familiarity. Builder et al. (1999) defined C2 as:

> “the exercise of authority and direction by a properly designated individual over assigned resources in accomplishment of a common goal” (cited in Jenkins et al., 2009a, p.9).

Jenkins et al. (2009a) went on to describe C2 as:

> “a collection of functional parts that together form a functional whole” (p.9).

The emphasis of NATO member states, and particularly the US and UK service doctrine developments, have in recent years focused on the utilisation of agile C2 systems in response to opportunities afforded by technological advances and challenges of modern counter-insurgence warfare (NATO, 2006; Alberts and Hayes, 2003; Gorman et al., 2006; DCDC, 2008; Hledik, 2009). The advances of technology and the increased pace of operations means that whilst data is often plentiful, it can be difficult to distinguish relevant information from irrelevant, as mission commanders constantly receive tactical updates (Kim and Hoffman, 2003; Cameron et al., 2009). To alleviate some of the pressures placed upon mission commanders technology has been applied to aid them in achieving and maintaining SA on the battlefield (McGuiness and Ebbage, 2002). SA has been recognised as an important part of performance in military land warfare (Stanton et al., 2009a). Understanding SA as part of C2 performance is therefore of interest to the wider military community.

Stanton et al. (2008) asserted that

> “command and control is a collection of functional parts that together form a functioning whole” (p. 11).

Team work in C2 systems can be distributed in nature and may involve both human and non-human actors (Gorman et al., 2006; Rafferty et al., 2012). Stanton et al. (2008) saw SA as emerging from team, or systems, interaction. They argued that this approach:

> “may help to promote a better understanding of technology-mediated interaction in systems” (p. 1288).

Distributed SA emerges as a result of information exchanges between parts of the system. Distributed SA is therefore an emergent property which is achieved through interaction or exchange. Such exchanges have been described as transactional SA and provide the means by which Distributed SA is developed and maintained (Rafferty et al., 2012; Stanton et al., 2006a). Skyttner (2001) took much the same position as Stanton et al. (2006a) who defined Distributed SA as ‘activated knowledge’. Communication therefore plays a key role in the development of Distributed SA in teams (Nofi, 2000). Indeed, Stanton et al. (2006a) proposed that:

> “it is not possible to have Distributed SA without communication” (p.1309).

They pointed out that the links between agents are more important than the agents themselves in maintaining Distributed SA. Effective team-working depends on information transfer, Distributed SA is therefore concerned with how information is used and distributed among agents in systems (Stanton et al., 2006a).

The systems approach may also be influential in highlighting shortcomings of SA in C2 teams; particularly with regards to its role in friendly fire incidents (Stanton et al., 2006a; Rafferty et al., 2012). The goal must be to understand and mitigate SA breakdown. Stanton et al. (2006; 2008; 2009a) similarly argued that measures of Distributed SA can enable interpretation and comparison of C2 systems. This is supported by Hue (2009) who pointed to the challenge which face the defence community in terms of understanding the characteristics associated with Network Centric Warfare (NCW). By enabling comparison between different C2 structures and assessment of technological innovations, assessments of Distributed SA may have a role in developing NCW capabilities. The ability to understand and influence Distributed SA in C2 systems, however, depends on the availability of data collection methods which are able to assess SA within the particular context of C2 environments.

Chapter 3 outlined research which has considered a wide array of measures for team SA (e.g. Salmon et al., 2008; Salmon et al., 2009c; Stanton et al., 2005). Little light, however, have as of yet been shed on measures of Distributed SA specifically for the context of the C2 domain. The characteristics of modern battlefield environments where stakes are high, time is pressured, the availability of information is complex and the circumstances are rapidly changing place considerable demands on C2 teams. These environmental characteristics also impact on the Distributed SA which emerge within the team. This chapter therefore poses the question of when Distributed SA should be assessed; before, during or after C2 activity. The review considers three data collection methods and focuses the review of these to criteria which may be used in qualitative cost-benefit judgments in order to select appropriate measures for local contexts. Costs are here to be understood in relation to the demands made on the C2 system or team, for instance what sort of access to personnel may be required. Benefits are considered in relation to the output, or the data collected.

A review is presented of three available data collection methods used to assess Distributed SA: the hierarchical task analysis (HTA; Kirwan and Ainsworth, 1992), communication analysis (Weil et al., 2008; Jentsch and Bowers, 2005) and the interview technique called the CDM (Klein et al., 1989; Klein, 2000; Klein and Armstrong, 2005). Each of these methods have a proven track record when it comes to assessment of Distributed SA and can be applied either before (HTA), during (communication analysis) or after (CDM) C2 activity. The data collected by either of the measures can be processed in the network analysis method for assessing SA (such as propositional networks or concept maps). This review does not consider data analysis in full and directs the reader to the literature for detailed instruction in the analysis of the data collected (see, for instance, Stanton et al., 2005; Kirwan and Ainsworth, 1992; Jentsch and Bowers, 2005; Weil et al., 2008). The three measures are considered with regards to their suitability for use in assessing Distributed SA in C2 environments and were evaluated against fourteen criteria:

1. Ability to reveal team interactions
2. Ability to depict the emergence of Distributed SA
3. Level of invasiveness associated with the measure
4. Time taken to administer
5. Reliability
6. Validity
7. Tools needed

8. Input into design/CADMID cycle (e.g. the concept, assessment, demonstration, manufacture, in-service and disposal) cycle
9. Resources and training required
10. Access requirements
11. Ability to assess compatible SA
12. Ability to describe SA transactions
13. Discerning between human and technical agents
14. Theoretical underpinning of the methods

These criteria were developed from the theory of Distributed SA, the characteristics of C2 environments and research methodology. Recommendations are also made as to the most appropriate time to utilise each method. In the following section the assessment criteria applied to compare the three Distributed SA data collection methods are considered.

4.2 Assessment criteria

Given the nature of C2 environments the measures used to assess Distributed SA must be conducive to administration in a manner which does not endanger mission performance yet still provides insight into Distributed SA.

Fourteen criteria were applied in considering the appropriateness of the techniques for assessing teams operating in complex C2 environments. These can be broadly grouped into three categories: Distributed SA relevant criteria, C2 relevant criteria and research methodological criteria.

4.2.1 Distributed SA relevant criteria

The first category concerns team interaction, emergent Distributed SA, input into design/CADMID cycle, ability to assess compatible SA, ability to describe SA transactions and ability to discern between human and technical agents. Team interaction refers to the activities agents perform to coordinate their activities. Emergent Distributed SA refers to the behaviour of the team or system which results from the interactions which takes place. Distributed SA is therefore a systems phenomenon and must be studied as such. Salmon (2009b) stated that:

> “collaborative systems possess cognitive properties (such as SA) that are higher than individual cognition” (p. 26).

Compatible SA refers to the finding that each agent's SA is different, i.e. not shared, for the same situation. This is due to agents utilising information available in different ways to complete their tasks. SA transactions ensure that the agents are aware of the common picture and through SA transactions individual agent's SA can be updated. SA transactions have been referred to as the glue which holds the system together (Stanton et al., 2006a).

4.2.2 C2 relevant criteria

The second category concerns: invasiveness, tools needed, time taken to administer and access requirements. Invasiveness refers to the potential impact the data collection process may have on military personnel, tools refer to the material required to execute the method and access refers to required access to military personnel.

4.2.3 Research methodological criteria

The third category concerns: reliability, validity, training and resources required and theoretical underpinnings of the methods. Reliability concerns whether the method can be replicated and give identical results whilst validity refers to whether the method is assessing the right thing (that is, Distributed SA). Training and resource requirements refer to basic instruction into administering the method whilst theoretical underpinning reflects the broader theoretical framework the method sits within.

The aim of this review was to compare the data collection methods against the fourteen criteria to establish when assessing Distributed SA are more efficient for the C2 domain. The next section describes the three Distributed SA data collection methods reviewed here.

4.3 Distributed SA measures

From a review of the literature, three data collection approaches appear to be suitable to assess Distributed SA: the HTA, communication analysis and the CDM. HTA has for instance been used to assess SA requirements for the design of systems (Young and Stanton, 2005). Communication forms an essential part of team collaboration and cooperation (Klein, 2000) and as a result communication analysis has been applied to assess SA in teams (e.g. Klein, 2000; Rafferty et al., 2010). Young and Stanton (2005) described interviews as a method for gathering general information which can provide insight into any kind of situation where an individual's perspective may inform an understanding of that situation. The CDM (Klein and Armstrong, 2005; Klein, 2000; Klein et al., 1989) sits within the category of interview techniques and has been applied to assess Distributed SA in teams (Young and Stanton, 2005; Stanton and Young, 1999a). In the following section each measure is described in more detail.

4.3.1 Before C2 activity – Hierarchical task analysis

The HTA was developed to analyse complex tasks, such as those in the processing industries (Annett, 2005). HTA analyses goals and operations as the means by which goals, rather than tasks, are attained (Annett, 2005). Stanton (2006) stated that the HTA output may be used to analyse systems by considering the goals of the system in detail. The HTA may also be applied to consider component parts of the system, including individual operator's tasks as well as those performed by teams. The HTA decomposes complex tasks into a hierarchy of goals, operations and sub-operations or plans (Annett, 2005; Stanton and Young, 1999a). The process of breaking complex systems, operations or tasks into its components means that the HTA is well equipped to identify areas which require improvement; either to training of operators or to the design of a system (Annett, 2005). The method has been utilised in a range of domains, such as process control (Patrick et al., 2006), the military (Stanton et al., 2008), human computer interaction (Baber and Stanton, 1996), team skills (Salas et al., 2004), training and human error and risk analysis (Annett, 2005).

For example, Salmon et al. (2008) utilised HTA to reveal SA requirements to inform the design of systems. They stated that an SA requirements analysis, where all the SA requirements of the end users are comprehensively identified and noted, should begin with a HTA. Data are collected from diverse sources, such as interviews with Subject Matter Experts (SME), training manuals and other manuals or documentation (Salmon et al., 2008). They further explained that following the HTA the relationship between different parts of the system, or team members', SA requirements can be identified by a graphical representation in a PN or a concept map. The aim of these depictions should be to identify:

> "what it is that needs to be known, how this information is used and what the relationships between the different pieces of information actually are—that is, how they are integrated and used by different users" (Salmon et al., 2008, p. 216).

This means identifying information which underlies Distributed SA and which represents compatible SA (that is, information used in different ways by different team members), what information are transactive SA (that is, information passed between team members) and what information can be both compatible and transactional in use (Salmon et al., 2009b). Salmon et al. (2009b) recommended consulting with SMEs to complete the last step. Considering Distributed SA, in terms of SA requirements, by assessing the system through a HTA, therefore allows system designers to group information meaningfully to support the development of Distributed SA in C2 systems (Salmon et al., 2009b).

4.3.2 During C2 activity – Communication analysis

It is presumed that effective communications are required for teams to successfully perform their tasks (Jentsch and Bowers, 2005). Weil et al. (2008) stated that:

> "communication is the choreography of team performance" (p. 277).

They further argued that the elements of collaboration which aids the emergence of team SA are available in the content of communication between team members (Weil et al., 2008). The content of team communication can therefore be observed and measured to gain insight into Distributed SA in operational settings where interviews or other intrusive measures are inappropriate (Weil et al., 2008). Communication content (that is, what is said) and communication flow (that is, who is communicating with whom), have been the focus of team research for some time (Weil et al., 2008). Several studies have focused on the importance of communication for team SA. For instance, Redden and Blackwell (2001) studied radio communications within a squadron which were categorised in terms of critical information based on a framework developed with SME. The data was subsequently analysed in terms of the extent to which the critical information was present in communication between the squadron members. Galliganl (2004) similarly reported a study in which communications were modelled to identify areas which benefit, as well as those areas which may be negatively affected, by the introduction of networking technologies in NCW. A further study was presented by Stanton et al. (2009a) who analysed communication types and patterns which took place between Brigade level Headquarters and geographically dispersed Battle Group Headquarters. They utilised both voice and digital communications in their analysis of a NCW system to assess the appropriateness of the organisations response to its environment.

4.3.3 After C2 activity – Interviews

Klein and Armstrong (2005) described the CDM as a semi-structured interview technique aimed at eliciting knowledge of decision making in naturalistic settings. The CDM:

> "applies a set of cognitive probes to actual non-routine incidents" (Klein et al., 1989, p.464).

Klein et al. (1989) argued that by allowing respondents to reflect on strategies they used in particular situations, and the decisions they made, a rich source of data can be exploited.

The CDM is most commonly used via face to face interviews; however, this manner of administration requires resources such as access to respondents over longer periods of time. Stanton et al. (2005) estimated that between 1–2 hours are required and describe the application time of this measure as medium. Given the limitations often placed on access to personnel in organisational settings researchers have adapted the CDM to allow for open-ended questionnaires to be administered, particularly in the military domain (Sorensen and Stanton, 2011: Rafferty et al., 2012). Such adaptations are advocated by Klein and Armstrong (2005) who argued that development of the CDM should be explored to maximise its potential. They suggested changing the execution of the CDM and combining it with other measures. Converting the CDM from a semi-structured interview to an open-ended questionnaire using the same cognitive probes are therefore not in breach of the integrity of the measure. This added flexibility has enabled application of the cognitive probes contained in the CDM to respondents who may otherwise not have been accessible to the traditional CDM administration. In addition to altering the administration of the CDM, Klein and Armstrong (2005) also suggested that changes to the probes themselves can be made if the operational environment requires it. It is clear that the HTA, as a Distributed SA data collection technique, may be applied before C2 activity, whilst communication analysis, by recording C2 team communications, may support evaluation of Distributed SA during C2 activity. The CDM, as a retrospective interview technique, can be applied to assess systems Distributed SA after C2 activity. In the following section the three measures are evaluated using the fourteen criteria described above.

4.4 Comparison of the measures

As has been established elsewhere (e.g. Salmon et al., 2008; Stanton et al., 2006a; Sorensen and Stanton, 2011; Weil et al., 2008; Salmon et al., 2009b) Distributed SA can be explored in terms of SA networks which show the knowledge contained by the whole system. SA networks and variations of such networks (such as propositional networks, information networks and concept maps) have therefore been applied as measures of Distributed SA. The three data collection methods described in this chapter (that is, the HTA, communication analysis and the CDM) provide raw data in the form of transcripts which can be used to develop SA networks or any of its variations (such as concept maps and information networks). The data collection methods are therefore hypothetically equal in the outcome provided, that is, in that each provides a network of relevant concepts or knowledge items. However, the data collection methods differ in terms of the collection technique which may result in significant differences in the structure of the networks and its content. Such differences can have consequences for our understanding of Distributed SA in C2 teams and for the recommendations regarding technical or organisational designs which are made. Comparing the three data collection methods to consider when Distributed SA should be measured relative to C2 activity is therefore important.

4.4.1 Distributed SA criteria

The Distributed SA criteria were: interaction, assessment of compatible SA, description of SA transactions, emergent Distributed SA, the ability to considering human versus technical agents and input into design.

The HTA enables an identification of the roles of agents, both human and technological, in the system through the sub goal descriptions. These show how the parts of the system must interact to fulfil the goal through executing the plans and completing the task, which in turn triggers further tasks. In this way, Salmon et al. (2009b) explained that the HTA can show coordination activity of team members as they seek to achieve team goals by identifying the information which will have to be sent, and received, by team members. Similarly, the HTA can show where SA transactions ought to, or must, occur in order to execute plans successfully. By describing the tasks and plans it also becomes possible to show where compatible SA ought to develop between team members. The HTA may show division of labour between human and technical agents and can highlight where technical agents may support the human agent. As such the HTA may be beneficial in the concept design phase of the CADMID process, or similar design cycle. This data collection method is limited, however, by describing the ideal system and cannot take account of what actually takes place within the system or team under study. The HTA may depict emergence of Distributed SA by tracing the triggering of, and execution of, plans to fulfil goals. In so doing the HTA provides an overview of systems level awareness in the form of a graphical depiction such as in a propositional network (Salmon et al., 2009b). The overview of system level awareness provided may prove incorrect; however, should the system trigger and execute plans other than those anticipated in the HTA, presenting an obvious weakness of the HTA.

The CDM, in turn, can reflect team members' interaction in that individual team members may refer to a particular colleagues, agents or roles in their CDM interview. However, where no such references are made there will be no evidence of interaction assessable in the data collected by the CDM. This means that some of the key aspects of Distributed SA could be lost. Without being able to reflect the interaction which takes place in the team, or system, the system level Distributed SA depicted cannot offer recommendations in terms of support for SA transactions or consider the impact of new technology on teams. The CDM can describe SA transactions, or infer them, by the references made to significant information and agent utilised during task performance. In other words, an agent who describes how they updated a status report detailing enemy movements and transmitted this to their team has provided their team with an SA transaction. This remains a retrospective description of SA transactions. The retrospective nature of the CDM makes it suited to the demonstration and disposal phases of the CADMID cycle, or similar design cycle, where it can extract Distributed SA relevant data from an already operating system to assess it with a view to modifying the system. Where a system is in a disposal phase of a design cycle a CDM may extract Distributed SA relevant data which can be used to establish knowledge transfer of the aspects of the system which had a negative or positive impact on Distributed SA. The CDM cannot assess technological agents which presents a limitation for its input to design and wider system understanding.

An added disadvantage of the CDM arises from the fact that not all personnel may be willing to describe the full extent of what took place during teamwork. For instance, if a particular team member failed to pass on vital information or made critical mistakes, other team members may prefer not to “grass” on their colleagues. Similarly, respondents may not detail their own shortcomings in team performance. Querying all agents which interacted during a task may remove this limitation and experienced interviewers are able to some extent to navigate sensitive issues and an assurance of anonymity also goes some way to set the conditions for an insightful exchange. The interview condition can, on the other hand, provide just the setting in which someone may feel able to divulge problems which concern them within the team or wider system. The CDM remains vulnerable to the preferences of the individual respondents, with the consequence that reliable interaction data may not appear in the transcripts.

The CDM provides an overview of the system level awareness, however, can only provide retrospective insight into Distributed SA. This means that the accumulated knowledge which was activated during task performance for the team can be gleaned from the network analyses method developed (such as propositional network, information network, and concept map).

In contrast, communication analysis reflects who communicated with whom and in so doing depicts the interaction which took place in the team. Indeed, by being able to show the directionality of SA transactions, communication analysis can both consider the flow and pattern of communication as well as the content. This provides a powerful means by which Distributed SA can be assessed and supported in C2 teams. For instance, by considering breakdowns in SA it may be possible to isolate agents or parts of the system that does not interact appropriately, thereby mitigating escalations leading to serious incidents such as friendly fire or accidents. As such, the communication analysis as a data collection method may inform the assessment and demonstration phases of the CADMID design cycle. This method can only assess technological agents by showing how technological agents are utilised in a system or team. For instance, a team member may use the radio to communicate or may refer to the GPS verbally in discussions with team members, or if "system logs" are recorded

(Walker et al., 2009a; Walker et al., 2009c; Stanton et al., 2009a; Stanton et al., 2008).These references may be utilised in design processes.

When applying the measure of communication analysis it becomes possible to not only provide a systems level depiction of awareness which have emerged retrospectively, but also to trace the way in which Distributed SA emerges over time. For instance by revealing the stages of coordination which the system, or team, went through and show how these stages occurred in conjunction with significant parts of task performance (such as dispatch of resources and critical decisions).

4.4.2 C2 criteria

The C2 criteria were: invasiveness, tools needed, time taken to administer and access requirements. In terms of invasiveness the HTA requires access to SME to verify and inform the descriptions of goals, sub goals and plans. However, the SME may be selected from higher echelons of the organisation or may include only one member of the team under scrutiny. Salmon et al. (2009b) and others (e.g. Annett, 2005; Stanton et al., 2005; Stanton et al., 2006a) advocated the collation of multiple HTA from other teams or systems to prevent replication of similar work. In this way, the invasiveness of the HTA may be kept to a minimum. The HTA, by virtue of being completed prior to C2 activity taking place, requires no input from personnel which may interfere with their task performance. It does, however, require the investment of time in proportion to the complexity of the task and analysis (Annett, 2005; Stanton et al., 2005; Stanton et al., 2006a). This means, in practice that HTA may be time intensive, however, the analyst may construct the analysis in such a way that the SME input is minimised, i.e. by consulting documentation and other known HTA outputs before approaching the SME. The tools needed for HTA are documents and procedures as well as observations of tasks being executed or similar “show and tell” exercises performed with SMEs. Access, in terms of, collecting Distributed SA data by the HTA method can be limited to a small number of SMEs (as few as just one person) who may not be involved in active duty or have other operational demands on them.

The CDM requires access to personnel after an event and preferably to all personnel from all areas of the team for a face-to-face interview and the measure cannot adequately consider technological agents. As such, this method is both invasive and places high demands on access. In C2 environments personnel are rarely inactive which may limit the times at which interview may take place. The longer the delay between task completion and the interview, the greater the chance of memory degradation (Robson, 2002). Further limitations of the technique are the cognitive probes of which many are not relevant to Distributed SA.

It is recommended that the CDM take between 1-2 hours (Stanton et al., 2005). Whilst the time taken to complete a CDM interview would vary by type of incident, and personality of the interviewee and interviewer, most interviews would require at least an hour to be meaningful. The use of an open-ended questionnaire would perhaps reduce the time taken to administer somewhat though not much less than an hour. Where an online open-ended survey has been developed, as described in the introduction, access may improve and the level of intrusiveness can be reduced. Amendments may also be warranted to rephrase probes to ensure relevance to Distributed SA. If meaningful data are to be gained, however, the response time by personnel would still have to be between 40–60 minutes. Pen and paper as well as recording devices are tools which may be needed if the method is conducted as an interview. Where the method is utilised as an open-ended survey these may be done using either online survey tools or printed versions.

Communication analysis requires minimal invasion where communication can be recorded. Both audio and textual communication may be recorded and later transcribed for analysis. Whilst some team members may be distracted by knowing that their communications are recorded in many instances this already occurs for safety reasons (that is, for use in accident investigations or for training purposes). Research has shown that individuals become accustomed to being observed, either through direct observation, video-recording or audio-recording, and that they continue as if they were not observed (Walker et al., 2009a). Therefore it can be expected that in a relatively short period of time, the recording of communications should not lead to undue distraction of personnel. However, to be successful the communication analysis method requires access to all communication which takes place between team members. This means that any radio communication and any face to face communication should be recorded. This data collection method requires little administration time during task performance, but does require preparation (such as set up of recording equipment and decision when and where to record activity). Considerable time may also be spent transcribing the recorded data. Resources required are a standard PC with word processing facilities. Additional resources such as transcription software may be of benefit but is not essential.

4.4.3 Research methodological criteria

The research methodological criteria were: reliability, validity, training and resources required, and theoretical underpinnings. The HTA is associated with low levels of reliability but with high levels of predictive validity (Stanton et al., 2005: Stanton and Young, 1999a). As a data collection method it is related to the cognitive task analysis method. It requires time intensive training and practice to be conducted well and practice in making decisions to end the development of an HTA is important as this must occur at the right level of detail. The CDM method is associated with low levels of reliability and its validity is also questionable (Klein and Armstrong, 2005; Stanton et al., 2005). In addition, the CDM probes are currently not entirely relevant to Distributed SA in that none explicitly probes for the interaction between agents and their environment (Walker et al., 2011; Salmon et al., 2009a). The method also requires that significant time is devoted to training and practice to elicit the richest possible data. Communication analysis is also associated with moderate levels of reliability but with high levels of validity (Weil et al., 2008; Jentsch and Bowers, 2005). No training is required for the administration of the communication analysis method, however, instruction is required to ensure that high quality transcripts are developed (such as how words meaning may be retained when taking them out of a spoken context).

Table 4.1 shows a summary of the comparison of the three Distributed SA data collection methods against the Distributed SA criteria, Table 4.2 shows a summary of the comparison against the C2 criteria, whilst Table 4.3 shows a comparison against the research methodological criteria.

Table 4.1. Summary of the comparison of the three methods against the Distributed SA criteria.

	Distributed SA Criteria						
C2 Activity	***Measure***	***Interaction***	***Emergent DSA***	***Input to Design/CADMIC Cycle***	***Ability to assess compatible SA***	***Ability to describe SA transactions***	***Human vs. Tech. agents***
Before C2 activity	Hierarchical Task Analysis	Identify through sub goals how team members must interact to fulfil goals through executing plans and by triggering sub goals.	Provide a prospective description of the possible emergence of DSA by tracing the triggering of, and execution of, plans to fulfil goals	Can be constructed for a concept design phase. However, cannot directly provide design solutions. Information required for firm design is inferred.	Can show where compatible SA ought to develop.	Can show where SA transactions ought to occur to execute plans.	May show the division of labour between human and technical agents. Can highlight where technical agents may support the human agent.
During C2 activity	Communication analysis	Can show which team members communicate with whom: i.e. flow and pattern of communications as well as the content of communication.	Reflect both retrospective system level DSA and can be used to trace the emergence of DSA over time.	Data collected may inform the Assessment and Demonstration phases, as well as disposal phase. Data may feed into design requirements and design specifications.	Can show the existence of compatible or incompatible SA.	Can describe SA transactions by tracing information exchange in the team or system.	Cannot access technological agents but may show how technological agents are utilised in a system or team.
After C2 activity	Critical Decision Method	Only reflect such mentions of interaction and other team members as the respondent offers in the CDM interview or open-ended survey.	Reflect retrospective systems level DSA.	Demonstration phase or mature designs. Data may feed into design requirements and specifications. May also be used in analysis design phase to assess designs, i.e. in the disposal phase to achieve knowledge transfer.	Can show which agents that had compatible SA or who had incompatible SA.	Describe SA transactions retrospectively.	Cannot access technological agents.

Table 4.2 Summary of the comparison of the three methods against the C2 criteria

	C2 Criteria				
C2 Activity	***Measure***	***Invasiveness***	***Access requirements***	***Tools needed***	***Time***
Before C2 activity	Hierarchical Task Analysis	Require SME's input to validate the analysis.	Access to documents (e.g. procedures) and personnel for enquiry and observation required.	Pen and paper.	SME's time required but can be limited by the use of other materials to input to the analysis.
During C2 activity	Communication analysis	Measure can be utilised where communication can be recorded in some form (i.e. voice or textual).	Access to voice or text recordings of communications.	Recording devices, transcription software aids where available.	Preparation and transcriptions of communications require significant time. No time required beyond normal task performance for personnel.
After C2 activity	Critical Decision Method	Require access to personnel.	Access to all relevant personnel required.	Pen and paper, recording devices.	1-2 hour interview.

Table 4.3 Summary of the comparison of the three methods against the research methodological criteria

	Research Methodological Criteria				
C2 Activity	***Measure***	***Reliability***	***Validity***	***Resources required, training required***	***Theoretical underpinnings***
Before C2 activity	Hierarchical Task Analysis	Associated with low levels of reliability (Stanton et al., 2005: Stanton and Young, 1999a).	High levels of validity (Stanton et al., 2005: Stanton and Young, 1999a).	Training and practice is time intensive.	Related to cognitive task analysis methods.
During C2 activity	Communication analysis	Associated with low levels of reliability (Weil et al., 2008; Jentsch and Bowers, 2005).	High levels of validity (Weil et al., 2008; Jentsch and Bowers, 2005).	No training required for data collection, however, instruction required to create high quality transcripts.	Related to qualitative analysis such as grounded theory and content analysis.
After C2 activity	Critical Decision Method	Associated with low levels of reliability (Klein and Armstrong, 2005; Stanton et al., 2005).	Low validity (Klein and Armstrong, 2005; Stanton et al., 2005). Validity for DSA further questionable given the many DSA irrelevant probes (Walker et al., 2011; Salmon et al., 2009a.)	Training and practice is time intensive.	Extension to the critical incident technique and related to cognitive task analysis methods, used in the naturalistic decision domain.

4.5 Discussion

By asking the question of when Distributed SA should be assessed; before, during or after C2 activity, this review has demonstrated that consideration must be given to the selection of appropriate data collection methods of Distributed SA for the particular context of teamwork within a C2 environment. The HTA, communication analysis and CDM have been used with success to depict Distributed SA in areas such as civil energy domain (Salmon et al., 2008) as well as in the military domain (e.g. Salmon et al., 2009c; Sorensen and Stanton, 2011; Stanton et al., 2009a; Stanton et al., 2006a). However, the suitability of these methods for the C2 environment has not been considered in detail. The aim of this review was therefore to compare the data collection methods on fourteen criteria to highlight the relative advantages and disadvantages of each measure for the particular challenges which faces teams operating in the C2 domain. It was asserted that given the highly changeable and information rich problem space which characterises modern battlefields (NATO, 2006) data collected for Distributed SA analysis must be able to reveal the interactions which take place between team members, depict the emergence of Distributed SA, whilst at the same time be non-intrusive and as time efficient as possible. The methods available to assess Distributed SA, in addition, lend themselves to assessment at different stages of C2 activity, with the HTA enabling assessment before, the communication analysis during and the CDM after such activity. The selection of appropriate data collection methods must therefore take not only the criteria relevant to the C2 domain into account but also consider the stage of C2 operational performance at which the method may be applied with the relative output the method can offer.

This review has shown that the HTA, which can be applied before C2 activity takes place, may highlight the areas where interaction ought to take place for optimal team performance and development of Distributed SA. Salmon et al. (2009b) pointed out that this has the added benefit of highlighting areas where technology may be utilised to support SA transactions within the system or team. Communication analysis, by virtue of recording teamwork during task performance, affords a real-time depiction of Distributed SA as it emerges through team interactions. The ability of the communication analysis, such as recorded in communication logs, to reflect emergent Distributed SA within C2 teams makes it a powerful tool for assessment in C2 environments. The CDM, on the other hand, provides an ‘after the fact’ image of C2 teams’ SA. In other words, the CDM shows the Distributed SA which did emerge for a team or system, rather than provide a tracing of Distributed SA as it emerges.

The quality of tracing the emergence of Distributed SA is one which is of particular relevance given the high pace of change and the distributed, decentralised and networked qualities which characterise modern C2 environments. Where changes occur rapidly it is vital that adaptations being made within the team can be outlined and the resulting impact this has on the developed Distributed SA.

When considering team interactions the HTA ensures that the goals which are interdependent between team members can be highlighted in advance of the activity. This means that the HTA may serve as a training tool for increasing the awareness of team members, in advance of operations, of areas where they must fulfil coordinating roles. The HTA can, in such instances, strengthen SA transactions in the team through team members increased understanding of the information needs of other team members. The HTA may also serve as an "ideal" against which performance can be assessed in terms of whether the team was coordinated in the required manner. It may also serve as a means by which weaknesses in the system can be highlighted and technological support may be directed. Conducting a communication analysis during C2 activity has the unique benefit of being able to reveal the important SA transactions which occur during teamwork. With this method it is possible both to consider the frequency of communications between team members and the pattern of communication associated with a team. Scrutiny of frequency of communication and patterns of interaction as advocated by, for instance, Jentsch and Bowers (2005). It can reveal areas where technology may support Distributed SA in C2 teams, or indeed it can be applied to assess the impact of new technology (Jentsch and Bowers, 2005). As such by using communication analysis it becomes possible to consider the role communication plays in the development of Distributed SA both in terms of good and inadequately developed awareness (Salmon et al., 2008). Hence, communication analysis enables an identification of the links between agents as advocated by Stanton et al. (2008; 2009a). This in turn enables a comparison of the relative performance of C2 structures (Stanton et al., 2008; Stanton et al., 2009a). The CDM may reveal the number of times individual respondents refer to specific team members or agents within larger C2 system; however, it cannot demonstrate objectively how the team members interacted to solve the tasks.

The importance of showing how teams exchanged SA transaction and interacted to enable Distributed SA to emerge is particularly acute for the C2 domain where SA breakdowns may lead to catastrophic consequences. The output of the measures should therefore be used to understand and mitigate SA breakdown and increase support for the development and maintenance of Distributed SA within the team and the C2 system as a whole. By assessing Distributed SA at the beginning of C2 activity it may be possible to influence battlefield technology design by specifying what functions the technology must have and how these should be allocated for optimal achievement of Distributed SA. The output of the data collection achieved with the HTA, for instance, may be usefully applied to inform design at the concept phase of the CADMID cycle or similar design process. By assessing Distributed SA during C2 activity, data collected may inform acquisition decisions concerning the use of existing technology to best support the system, and by assessing Distributed SA. The communication analysis lends itself to collect data that may be used in the assessment and demonstration phases of the CADMID design cycle. By collecting Distributed SA data after C2 activity, it may be possible to inform future operational use of battlefield technologies to support Distributed SA. This can be done by the use of a retrospective data collection method, such as the CDM, which may feed into the demonstration and disposal phases of the CADMID design cycle. In this way the data collection methods are not only linked with the stages of C2 activity but can be related to parts of the CADMID design cycle or similar design processes.

Military personnel are by the nature of the operations they perform mostly inaccessible. Rarely can personnel be spared for lengthy discussions on the goals of their activities or for face-to-face interviews; in addition interruption of performance during operations could have dire consequences. As such, any data collection methods applied to assess Distributed SA must be non-invasive and time efficient. The HTA could potentially be quite invasive by engaging all team members in informing the hierarchical development of the goals, sub goals and plans. However, the analysis can be constrained to include only one SME. Additionally, as the analysis takes place before C2 activity it can limit the intrusion considerably. Where communication logs may be recorded either as voice or text this method presents the least intrusive option and recordings can capture communication which takes place naturally within the C2 team. This also renders the communication logs as the least time intensive measure, despite requiring a significant time spent in transcribing the communication data, as it does not require the use of personnel time directly. The CDM considered here may be converted to open-ended questionnaires to allow administration between tasks and to limit the response time required as has been done elsewhere (Rafferty et al., 2012; Sorensen and Stanton, 2011).

This review has considered three measures of Distributed SA specifically for the C2 domain taking into account its particular challenges in comparing the methods against fourteen criteria. Each method on their own has proven useful as data collection tools for Distributed SA in the military domain (Sorensen and Stanton, 2011; Salmon et al., 2009b; Stanton et al., 2009a). Whilst it is relevant to discuss the methods separately it should be noted that where possible combining the methods may provide the most comprehensive results (Stanton et al., 2005). In this way the HTA can detail what ought to be achieved, the communication analysis can consider what takes place, whilst the CDM can allow personnel to reflect on what took place. Combining methods are, additionally, in keeping with Human Factors practice (Salmon et al., 2009b). Should it not be possible to combine methods, however, analysts should consider the selection of Distributed SA data collection methods in relation to when the method can be administered and the expected outcomes of the method as revealed here for the fourteen criteria. As such, if intrusion and time demands are less critical, for instance during training exercises, combining the CDM with communication analysis would give the added benefit of the reflections of the personnel on their and team members actions. If the aim of the analysis is to consider where technology may best support C2 team's coordination activities to mitigate SA breakdown, a combination of the HTA and communication analysis may be preferred. Considering each of the three measures against all fourteen criteria overall it becomes clear that where only one data collection method is feasible the use of the communication analysis method would give the greatest advantages. This is due to the methods ability to input into larger parts of the CADMID cycle, its potential to allow real time tracing of team interaction and SA transaction, and by extension, revealing how Distributed SA emerges over time. In addition this method is associated with the least impact on military personnel despite requiring access to communication and high demands on the staff who must transcribe the material.

This review has shown that the HTA reveals the areas of interaction and emergence of Distributed SA which are latent in a system and may highlight areas in need of support or improvement through system design. Communication analysis, on the other hand, reveal the teams' Distributed SA as it emerges and enables a comparison between C2 structures as suggested by Stanton et al. (2008; 2009a). The CDM in turn enables a retrospective insight into the overall systems awareness which emerged and can provide important insights into relevant personnel's reflection on their performance. Assessment of Distributed SA in C2 teams remain an important area for researchers and practitioners as either measure may inform technology development, selection of C2 structures, training and doctrine, as advocated by NATO (2006) and the United Kingdom (UK) Ministry of Defence (MOD) Development, Concepts and Doctrine Centre (DCDC) (2008).

4.6 Conclusion

Distributed SA has been established as a key part of C2 performance, in particular the role of SA breakdown in human error and fratricide has led to an increased interest in the phenomenon. This chapter has presented a review of three measures for assessing Distributed SA in the C2 domain: the HTA, communication analysis and CDM. It was asserted here that measuring Distributed SA in C2 environments requires unique attention as the ability to understand weaknesses of C2 teams' development of Distributed SA can influence the adoption of technology and training of such teams to improve battlefield performance. C2 teams require efficient information sharing and interaction to achieve Distributed SA, team interaction is therefore a vital aspect of both Distributed SA and C2. As such, measures of Distributed SA must enable a representation of the interactions which takes place within the team and between human and technological agents. The HTA was shown to be able to provide an overview of the interconnectedness of goals in the team and as such may highlight areas where teams may have compatible SA and where SA transactions are likely to take place. The HTA can therefore both be useful to inform system design and as a check against C2 teams performance. The utility of the CDM lies in its ability to reveal the overall systems awareness which has emerged. The communication analysis has an advantage in that records of communication can highlight areas where technology and training may be required to maximise the C2 structure's potential. This can be done by reflecting frequencies and patterns of communication between team members. Further research should consider the utility of each of the three measures on their own as well as in combination in order to assess all aspects of C2 activity.

This chapter has considered three data collection techniques utilised in assessing Distributed SA in teams and when these should be applied. The data collection methods considered here; e.g. the HTA, the CDM and communication logs may all feed into the network analysis method. Chapter 5 builds on this review by considering the reliability and validity of communications and the CDM to further contribute to the body of knowledge concerning the measurement and analysis of Distributed SA. The HTA, as a means by which an "ideal" of performance can be provided, will be used as a benchmark for the validity of the CDM and communication analysis. This is done by providing evidence supporting the use of a software tool in network analysis and further evidence of the reliability and validity associated with the CDM and communication logs. A study of inter-rater reliability was devised to assess the level of agreement between independent raters and the analyst. Chapter 5, further, considers the reliability of a software tool which can be utilised in network analysis by comparing the words the software extracts from the CDM and communication logs to those extracted by the analyst and independent raters. The two data collection techniques were then compared in terms of the extent to which they revealed the same information content as predicted by a HTA. Validity was then computed using the signal detection paradigm. These findings may support researchers in their selection of data collection measures aimed at assessing Distributed SA by highlighting the reliability and validity of the CDM and communication logs.

5 Inter-rater Reliability and Criterion-referenced Validity of Measures of Distributed SA

5.1 Introduction

This chapter builds on the review presented in Chapter 4, which considered three data collection techniques, e.g. the HTA, the CDM and communication analysis. Two of these data collection techniques; the CDM and communication analysis, feed into the network analysis method which enables assessment of Distributed SA in teams. To support the selection of data collection technique, the reliability and validity associated with them ought to be explored. This chapter therefore presents an empirical study in which the inter-rater reliability and criterion-referenced validity of these two measures were examined. The chapter aims to support the research community in the utilisation of the network analysis method, and associated data collection techniques, to assess Distributed SA in teams. In so doing the study sought to advance the theory of Distributed SA by furthering the measurement of the phenomenon.

Research has shown that SA plays an important role in individual and team performance (Patrick and Morgan, 2010). As a consequence, the phenomenon has received attention from a number of fields ranging from transport (Walker et al., 2011; Golightly et al., 2010; Gugerty, 1997), process control and nuclear (Patrick et al., 2006; Patrick and Morgan, 2010) and medicine (Fioratou et al., 2010) to the military (Salmon et al., 2009b). Most recently, the theory of Distributed SA has renewed the interest in the phenomenon within the Human Factors community (Stanton et al., 2006a). Distributed SA is founded in the theoretical domains of System Ergonomics (Clegg, 2000) and distributed cognition (Stanton et al, 2010a). Distributed SA has been found to enable a comparison between systems, or teams, such as different C2 systems (Stanton et al., 2008; Sorensen and Stanton, in press) and aircrew (Sorensen et al., 2011). Stanton et al., (2006b) described SA as:

> “a dynamic and collaborative process binding agents together on tasks” (p.1288).

SA therefore becomes an emergent property which arises from team member’s interaction with each other and artefacts in the world (Stanton et al., 2006a). The emergence of Distributed SA occurs when parts of the system, such as team members, exchange information relevant to the situation (Salmon et al., 2009b). This is in line with Gorman et al. (2006) and Artman (2000) who described SA as an interaction-based phenomenon. Stanton et al. (2006b) described these communication acts as transactional SA. Salmon et al. (2010) presented transactional SA as the process by which Distributed SA is acquired and maintained. They explained that a transaction represents an SA exchange between team members. For instance, the exchange of information in the team leads to transactions of awareness (Salmon et al., 2010). It is therefore possible to compare teams or systems in terms of the nature of their transactions (Sinclair et al., 2012) and the resulting emergent Distributed SA.

The interest in the phenomenon of SA, as highlighted in Chapter 3, has led to significant efforts being invested in developing measures to accurately assess it, resulting in a wide range of measurement techniques (Nofi, 2000). One class of measures, network analysis, has been applied in a number of areas as a means of assessing and representing Distributed SA. Given the role Distributed SA has been found to play in dynamic teamwork (Artman, 2000; Stanton et al., 2006a; Stanton et al., 2008; Salmon et al., 2009c) it is important to establish the reliability and validity of the methods. Ensuring that scientific measures have high levels of reliability and validity is vital to support the utilisation of such measures in practice (Caple, 2010). This chapter considers the validity of two data collection techniques which are used to collect Distributed SA data, which in turn, is analysed using a network method. The chapter further considers the reliability of the network analysis method. In the next section the method of network analysis is considered in more detail as a means of assessing and representing Distributed SA.

5.1.1 Network analysis as a means of assessing and representing Distributed SA

Network analysis, or information networks, has been suggested as a way of representing systems awareness (Weil et al., 2008). Stanton et al. (2008) have argued that:

> "knowledge [or information] relates strongly to the concept of SA" (p.22).

They go on to explain that a systems view of SA, or an individual view, can be understood as activated information. This is what network models seek to depict; information which has been activated by individual agents, both human and technical, over the course of task performance and time (Salmon et al., 2009b). Stanton et al. (2008) pointed to an advantage of network analysis in that:

> "they do not differentiate between types of node (for example, knowledge related to objects, people or ideas) so that from a modelling perspective they are not constrained by existing structures of people and objects, rather to the required knowledge elements associated with a scenario" (p.23).

Network analysis has therefore been shown to have considerable advantages when it comes to assessing and modelling Distributed SA. For instance, applying a network analysis approach means it is possible to reveal active and non-active information (Stanton et al., 2008). Stanton et al. (2008) explained that this can be done when the task is known (i.e. explained by subject matter expert or revealed by a hierarchical task analysis) by dividing a task into phases so that information which should be active in a particular task phase can be distinguished from information objects which were not activated. Furthermore, network analysis has the ability to:

> "reveal the emergent property of SA as it relates to 'key aspects of knowledge'" (Stanton et al., 2008, p.23).

The advantages of the network analysis approach in assessing Distributed SA shows that the method is well suited to assessing the phenomenon. In addition, the method has been utilised in a range of other fields, such as in anthropology, sociology and psychology, and is considered systematic and rigorous (Salmon et al., 2009b).

Network analysis consists of different forms of network models, such as concept maps, propositional networks, information networks and semantic networks. Of these, concept maps and PNs have been the most frequently applied to assess SA, as described in Chapter 3. PNs, for instance, have been applied to analyse Distributed SA in a range of domains, such as the medical domain (Flin et al., 2002), railway (Walker et al., 2006) and energy domains (Salmon et al., 2008). Concept maps have similarly been applied in the military domain with success (Stanton et al., 2006a; Rafferty et al., 2012; Sorensen and Stanton, 2011). Both PNs and concept maps (see Figure 5.1 for an illustration) are used to represent information which has developed, or emerged, within a team or system (Salmon et al., 2009c). This is done by depicting concepts and the relationship which exists between them. For instance, Salmon et al. (2009b) proposed a PN methodology as a way of describing a system SA. They stated that:

> "it depicts, in a network, the information underlying a system's knowledge, the relationship between different pieces of information and also how each component of the system is using each piece of information" (p.60).

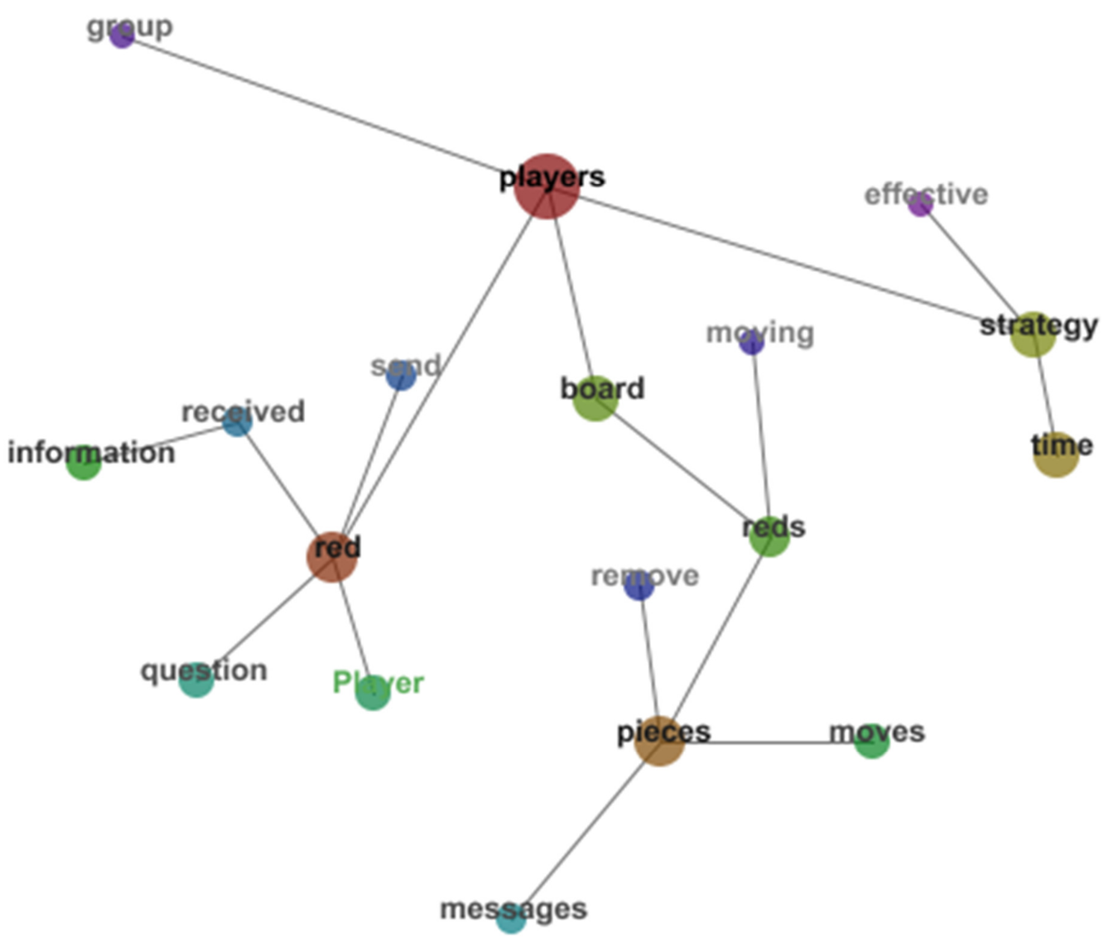


Figure 5.1 Exemplification of a concept network

Figure 5.1 illustrates a concept map which was developed from an experimental team at the end of their task performance. The team appears to be aware of a number of important aspects of the game, such as "strategy", "time" and "moving". The concept map shows the concepts which had the higher significance to the team in larger nodes, whilst the lines indicate which concepts are connected to each other.

Salmon et al. (2009b) explained that Distributed SA is represented as information elements, or concepts, and the relationship between them. This refers to the theoretical framework of network analysis which is based on the principle that language and information can be shown in maps or networks of concepts (Weil et al., 2008). Salmon et al. (2009b) point to the wide use of network analysis in other domains, such as in the form of semantic networks, which are used to represent associations between items within a concept. Semantic networks are defined as:

> "a graphic notation for representing information in patterns of interconnected nodes or arcs" (Sowa, 1991, p. xii).

Sowa (1991) further stated that:

> "…network analysis focuses its attention on social entities or actors in interaction with one another and on how these interactions constitute a framework or structure that can be studied and analysed in its own right" (p. xii).

This is in accordance with the notion underpinning Distributed SA: which sees SA as a systems phenomenon and therefore requires that all parts of the system are assessed (Stanton et al., 2006a; Stanton et al., 2009d). The advantage of network analysis is therefore that these may depict a system's awareness (Salmon et al., 2009b). This is done by representing the use of different information by both human and non-human agents, as well as the contribution these agents make to the systems overall awareness (Salmon et al., 2009b).

The underlying principles of the network analysis method are qualitative and it is therefore associated with weaknesses common for qualitative methods, such as concerns for reliability and validity. The network analysis method is, furthermore, time intensive (Houghton et al., 2006). To limit the time involved in network analysis software tools have been developed, such as the Leximancer™, with associated strengths and weaknesses. These issues are addressed in the following three sections.

5.1.2 Reliability of methods

The phenomenon of Distributed SA has been accepted as an important construct which explains much of team performance and the way in which a system operates in their environment (Salmon et al., 2009b). Measurement of Distributed SA therefore has the potential to inform the design of systems and technology; however, this can only take place if the analysis process and the findings of Distributed SA can be trusted. This trust is dependent on two things: the application of a systematic and sound analysis process and this analysis methods reliability (Stanton and Young, 1999b). In other words, that the Distributed SA which was present in the system at the time of data collection is represented in the same way by all potential researchers. This is vital not only to be able to trust the findings of Distributed SA but also to enable a comparison between teams and systems in terms of the Distributed SA which has emerged. This is supported by Patrick et al. (2006) who argued that:

> "team comparisons are important, as they will provide insight into the phenomenon of SA and the extent to which effects are generalizable or situation specific" (p. 389).

Studies reported elsewhere have shown that Distributed SA can be successfully assessed using a variety of data collection methods (Sorensen and Stanton, 2012) and analysed in a rigorous manner by the application of network analysis (Salmon et al., 2009b).

Salmon et al. (2009b) stated that when focusing on the measurement of SA for real world tasks inter-rater reliability has the most value;

> "that is, any method used should be reliable regardless of the analyst using it" (p.37).

Inter-rater reliability refers to whether different analysts will produce the same results when applying the same method to the same data material. Researchers and practitioners interested in SA often carry out their investigations in naturalistic environments, e.g. they examine SA in teams performing real world tasks, in real time. This means it is difficult to ensure that the team context is exactly the same, however, once data has been collected it should be possible to assume that the findings, if analysed by the same systematic method, will provide the same answers, i.e. have high inter-rater reliability. Similarly, Annett (2002a) argued that methods should

> "attempt to minimize disagreement between independent observers" (p.971).

In accordance with Marques and McCall (2005) comprehensive review of inter-rater reliability and the work of others (Jentsch and Bowers, 2005; Dockrell et al., 2012; Green et al., 2012; Bysari et al., 2011), agreement of 80% or above between the raters and analyst has been deemed acceptable when reliability is calculated as the number of agreements divided by the total number of agreements and disagreements. Agreement over 80% between raters in qualitative analyses provides an indication that the coding framework used has been applied in a consistent and reliable manner (Jentsch and Bowers, 2005; Dockrell et al., 2012; Green et al., 2012; Bysari et al., 2011). The reliability criterion has been widely applied in research elsewhere (e.g. Crichton and Flin, 2004; Crichton, 2009; Bysari et al., 2011; Rafferty et al., 2012). This chapter therefore focuses on inter-rater reliability and applies the criteria of above 80% agreement as the acceptable level of agreement to the reliability data. In the following the validity of Distributed SA methods are considered.

5.1.3 Validity of methods

Validity may be considered in a broad sense as:

> "the degree to which a test or some other measurement device measure what it is supposed to measure" (Proctor and Van Zandt, 2008, p.569).

Salmon et al. (2009b) stated that:

> "of the many different forms of SA measurement approaches available, the majority are belied by flaws, which affect their validity and utility when used to assess team SA" (p.493).

Salmon et al. (2009b) noted that most of the available SA measurement approaches do not account for the mapping between SA elements, nor generalise well to real world tasks. The measurement approaches which have been shown to have a high degree of validity (e.g. freeze probe techniques such as the SAGAT) may therefore not be appropriate for the assessment of Distributed SA in teams. The difficulties concerned with assessing the validity of SA measures are due to the difficulty in ascertaining what the situation looks like (Salmon et al., 2009b). An objective view of the situation would have to be known so that the SA of the team could be compared to the "true" situation (Nofi, 2000). There is rarely an ideal, however, which can be used as a benchmark against which the observed SA can be assessed (Salmon et al., 2009b). This issue pertains to concurrent or criterion-referenced validity. Criterion-referenced validity measures the relationship between predicted results and observed results for a method (Stanton and Stevenage, 1998; Baber and Stanton, 1996) . Criterion-referenced validity therefore determines the extent to which the predictions were comparable to actual outcomes (Stanton and Young, 2003).

As discussed in Chapter 4, HTA is a potential method which can be used to construct a predicted outcome of tasks. This can then be compared to the observed outcome of the tasks performed. This enables a description of performance of a system, both in terms of team work and non-human agents (Stanton, 2006). HTA's has been applied elsewhere to serve as a means of comparing predicted, or typical, behaviour against observed behaviour (e.g. Stanton et al., 2008, Stanton, 2006; Kirwan and Ainsworth, 1992). Constructing a HTA of the way in which teams perform a task and depicting the predicted concepts that team will have developed as a result of their task performance in a "prototypical" concept map therefore serves as a means by which the validity of two data collection techniques; communication transcripts and the CDM (Klein and Armstrong, 2005), can be considered. The two data collection techniques were scrutinised in terms of the extent to which they revealed the same information content that was predicted. Validity was computed using the signal detection paradigm to provide a hit rate (HR; Dekker, 2012; Stanton et al., 2009b, Stanton et al., 2011a). The signal detection paradigm has been found to be useful in testing the power of Human Factors methods, such as Human Error Identification (Stanton et al, 2009a; Stanton et al., 2009b; Demagalski et al., 2002; Stanton et al., 2006b; Dekker, 2012) and enables a ratio to be calculated from the number of concepts observed against the number of concepts that were predicted but not present. The observed concepts which were predicted therefore constitute 'hits' and the concepts which were predicted but not found 'misses'. Hit rate was calculated as hit divided by hit plus miss.

Recently, software has been developed to aid researchers and practitioners in the analysis of qualitative data and in conducting network analysis. These software tools hold considerable promise in terms of formalising the analysis process through the use of algorithms. For the purpose of the present study Leximancer™, a text analytic tool, was chosen to support the network analysis and is described below.

5.1.4 A software tool for network analysis: Leximancer™

Smith and Humphreys (2006) pointed out that human decision makers may be subject to influences that they are unable to report. In order to mitigate subjectivity in human analysis significant resources in terms of time and costs must be invested (Smith and Humphreys, 2006). Codes must be validated, coders must be trained and inter-rater reliability must be tested to ensure the reliability of the findings (Smith and Humphreys, 2006). Automating the coding process therefore has the potential to reduce costs considerably (Smith and Humphreys, 2006), and thereby allows network analysis to be applied more widely by researchers and practitioners alike. Reducing costs whilst maintaining reliability and validity is crucial to Human Factors practitioners (Stanton and Young, 1999b). Smith and Humphreys (2006) argued that using an automated system like Leximancer™ also allows for reanalysis of text without considerable further invested resources, and it enables large quantities of text to be analysed, going beyond quantities which could be reasonably analysed by a human analyst.

Leximancer™ is a text analytic tool which:

> "can be used to analyse the content of collections of textual documents and to display the extracted information visually. The information is displayed by means of a conceptual map that provides a bird's eye view of the material, representing the main concepts contained within the text as well as information about how they are related" (Leximancer, 2010, p.4).

Leximancer™ uses algorithms for automatically selecting, learning and adapting a concept from the word usage within a text (Smith, 2003). An asymmetric scaling process is then applied for generating a map of concepts based on co-occurrence in the text analysed (Smith, 2003). The use of algorithms ensures that data is treated in the same way, regardless of how many times it is analysed, or by whom. The programme therefore has the advantage of removing some of the subjectivity in the coding process involved in constructing the networks, whilst at the same time allowing the researcher to interpret the findings in light of the local context in which the data was gathered. The automatic processing reduces the time taken to code the transcripts, though time must still be invested in creating transcripts to enable coding. Studies using Leximancer™ report a high level of inter-rater reliability when compared to manual coding. For example, Gretch et al. (2002) compared manual coding with the automatic coding in Leximancer™ and found near identical results (ranging from 84% - 89%) for 177 reports. Similar results are reported by Rafferty et al. (2012) and Walker et al. (2011). In the following section the inter-rater reliability and validity study is described.

5.2 Method applied for the experimental study

5.2.1 Participants

A sample of 25 was drawn from the general student population of the University of Southampton to take part in the experiment. The inclusion criteria for participants were fluency in English and proficiency of using instant messaging software such as Microsoft Messenger™ (MSN). Permission to conduct the study was sought and granted by the University of Southampton Ethics Committee. Participants were voluntarily recruited by responding to a recruitment email sent to all students of the University of Southampton and given £10 for travel expenses. Volunteers who met the inclusion criteria were randomly allocated to teams of five and a total of five teams were created.

Two further participants, who had not taken part in the experiment, were used as raters for the inter-rater reliability study. These two participants were drawn from the postgraduate student population to ensure some general knowledge of Human Factors research methods.

All experimental teams had 4 males and 1 female member with mean age ranging from 19.2 to 29 years. The two raters were both postgraduate students and 25 and 26 years of age respectively. All experimental participants were fluent English speakers and frequent MSN users whilst the raters had undertaken general research skills courses as part of their postgraduate training.

5.2.2 Experimental design

A study was developed to address the two issues described in detail above, namely the need for further empirical consideration of the reliability and validity of network analysis for assessing Distributed SA and the utilisation of a software tool to aid such analysis. An inter-rater reliability test was performed to consider the reliability of network analysis and the software tool chosen to support the analysis (e.g. Leximancer™). Data was collected, transcribed and processed in the Leximancer™ for automatic coding and the development of concept maps. Two levels of analysis were considered for the inter-rater reliability data; the starting point for the analysis (e.g. the extraction of words from transcripts) and the end point (e.g. the categorisation framework applied to interpret the concepts developed and presented in a map). Both levels of analysis were compared to determine the level of agreement between the analyst and two additional independent coders. The starting point of the analysis was chosen as the words extracted by Leximancer must be comparable to those chosen as key words for further coding by the researchers. This part of the inter-rater reliability study therefore subjects the Leximancer software tool to a test of reliability.

A test of validity was performed by creating HTA's of four experimental tasks and was used to generate a "prototypical" concept map based on the predicted information the teams would have after performing the task. The prototypical concept map was compared against the observed concept maps for each of the five experimental teams on each task. The five experimental teams were organised into one of five organisational structures: the Chain, the Y, the Circle, the Wheel or the All-connected (Bavelas, 1948, Leavitt, 1951; Walker et al., 2009d). For a full description of the organisational structures see section 6.2.2. The following section describes the experimental tasks that the five experiment teams performed.

5.2.3 Experimental tasks

A strategy game was developed in which a chess board was used with players of four different colours; blue, yellow, green and red. The blue players signified friendly players and were controlled by the experimental team. Yellow players were unknown, while green were neutral and red players were enemy or opponents pieces. The rules of the game were as follows:

- The aim of the game is to take as many red players as possible
- Each Blue player has one move per turn, however, each player can give their move to another player on a turn-by-turn basis
- Each player can move in any direction but not through another player
- Moving through another player constitutes taking
- Blue players have to outnumber a red player before they can take it
- Blue must not take blue, green or yellow players
- Red must move away from blue if a blue player gets to within one space of red

- If red players outnumber the blue players they must move towards them and try and take them
- In two games the opponent players move
- In two games the opponent players are disguised as yellow and will only reveal their true colour (e.g. red or green) if a blue is next to it.
- Changing colour is considered a move (the player cannot immediately be moved after colour change). After revealing the colour the player cannot change back to yellow.

A military SME verified the game as reflecting those strategy games used in command training. The four games played were:

- Static game: The opponent players do not move. All opponent players are shown to the experiment team in their true colours (e.g. red is shown, yellow is shown and green is shown)
- Moving game: The opponent player's move after the experiment team has moved. All opponent players are shown to the experiment team in their true colours (e.g. red is shown, yellow is shown and green is shown)
- Static and disguised game: The opponent players do not move. All opponent players are shown as yellow (e.g. red and green are disguised as yellow) so that the experiment team must reveal what the true colour of the opponent players are (i.e. green, red or yellow).
- Moving and disguised game: The opponent player's move after the experiment team has moved. All opponent players are shown as yellow (e.g. red and green are disguised as yellow) so that the experiment team must reveal what the true colour of the opponent players are (i.e. green, red or yellow).

A HTA was developed for the four games, as shown in Figure 5.2.

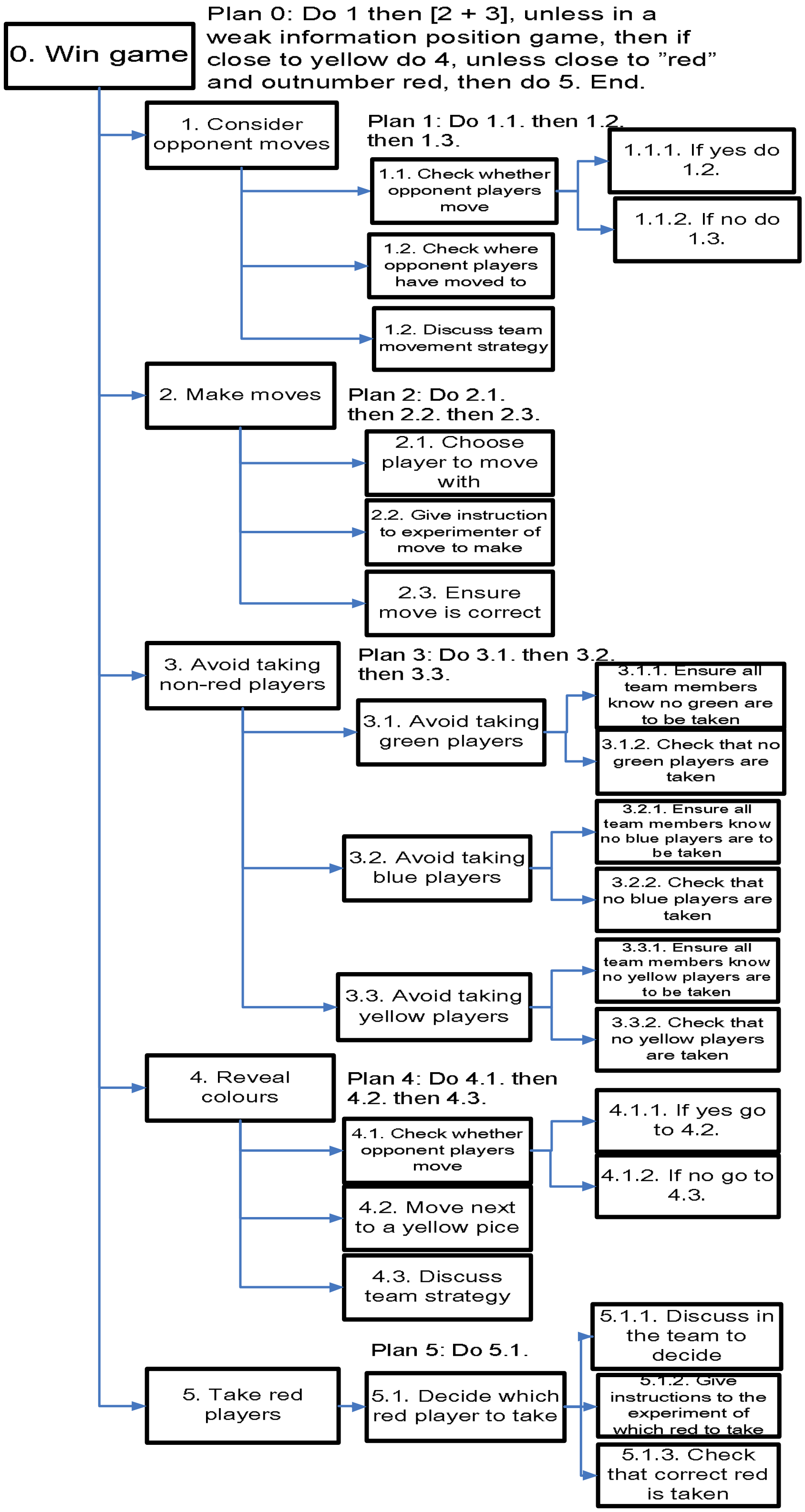


Figure 5.2 HTA developed for the experiment games

5.2.4 Hardware, software and workstations

The experimenter used a standard laptop, monitor and keyboard to control the experiment. Five PC notebooks with monitors and keyboards were set up in five individual cubicles partitioned with black foam boards. Participants were also issued with hearing protectors to prevent distractions and to encourage immersion in the game. The experimental environment can be seen in Figure 5.3.

Figure 5.3 Experimental environment

A webcam was used to continuously stream a live video of the chess board from the experimenter's laptop. This video was shared with participants using a virtual meeting hosting site. Figure 5.4 shows a screen shot of a participant computer screen with the webcam image in the left hand corner and the MSN window in the right hand corner.

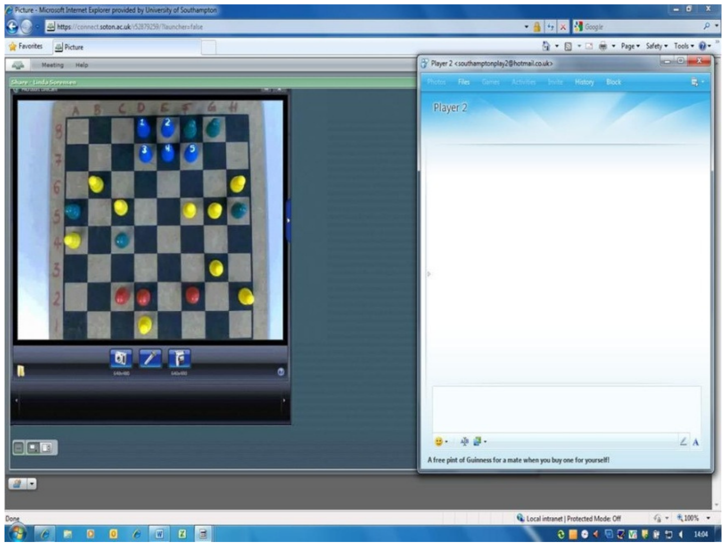


Figure 5.4 Example of participant computer screen

5.2.5 Measurement

Team communications were recorded by using the history function in MSN which saves a communication log. In addition, an online questionnaire of the CDM was created using iSurvey, an online survey hosting site provided by the University of Southampton. AS discussed in Chapter 4, the CDM is an information elicitation technique which has been applied in order to collect data on Distributed SA with success elsewhere (e.g. Salmon et al., 2009b; Sorensen and Stanton, 2011). The questionnaire was administered after each of the four games.

Inter-rater reliability

All data collected (from the communication logs and the CDM) were transcribed and Leximancer™ was used to develop concept maps from the transcripts. The words extracted from the transcripts were compared to the words extracted by the analyst and two coders in order to perform an inter-rater reliability test between the human analysts and the automatic coding provided by Leximancer™. The concepts produced by Leximancer™ were subsequently categorised as either relevant or irrelevant according to the game rules (see Table 5.1) and the percentage agreement was compared for the analyst, coder 1 and coder 2 and between coder 1 and coder 2. The categorisation framework was applied for the data collected for each method (e.g. the communication data and the CDM). Kendall's tau-b was calculated to test the statistical significance of any agreement revealed (Field, 2009). The statistic is expressed as a value between 0 and 1, the closer to 1 the higher the agreement between the raters (Field, 2009).

Table 5.1 Categorisation framework of relevant concepts

Agree	Decide	Illegal	Opponents	Reveal	Take
Ask	Disguised	Inappropriate	Outnumber	Round	Tell
Blue	Donate	Irrelevant	Pass	Rules	Time
Board	Eat	Kill	Paste	Same	Told
Bottom	Expose	Legal	Plan	Screen	Turn
Capture	Forfeit	Line	Player	Seconds	Win
Choose	Game	Location	Players	Similar	Winning
Colours	Give	Minutes	Quick	Square	Won
Column	Go’s	Move	Quickly	Strategy	Yellow
Confirm	Goes	Moving	Red	Suggest	Yes
Coordinate	Green	Okay	Reds	Surround	
Copy	Hurry	Opinion	Repeat	Tactics	

Validity

The data material from the communication logs and the CDM were further considered against four concept maps developed from the HTA (see Figure 5.2) in order to consider the validity of the observed concept maps developed by Leximancer. The predicted concept maps are shown in Figure 5.5, Figure 5.6, Figure 5.7 and Figure 5.8. Some concepts, such as "move", "take" and "red" would be expected to appear in all concept maps regardless of which game was played given that the team members must move to take the red. There are some concepts, however, which ought to be unique for a given game condition, such as "moving" in the moving game and the moving and disguised game (where the opponent pieces move, see Figure 5.6 and Figure 5.8). Furthermore, the "reveal" is only expected to appear in the concept maps of the static and disguised game and the moving and disguised game, where the opponent colours are all shown as yellow (see Figure 5.7 and Figure 5.8).

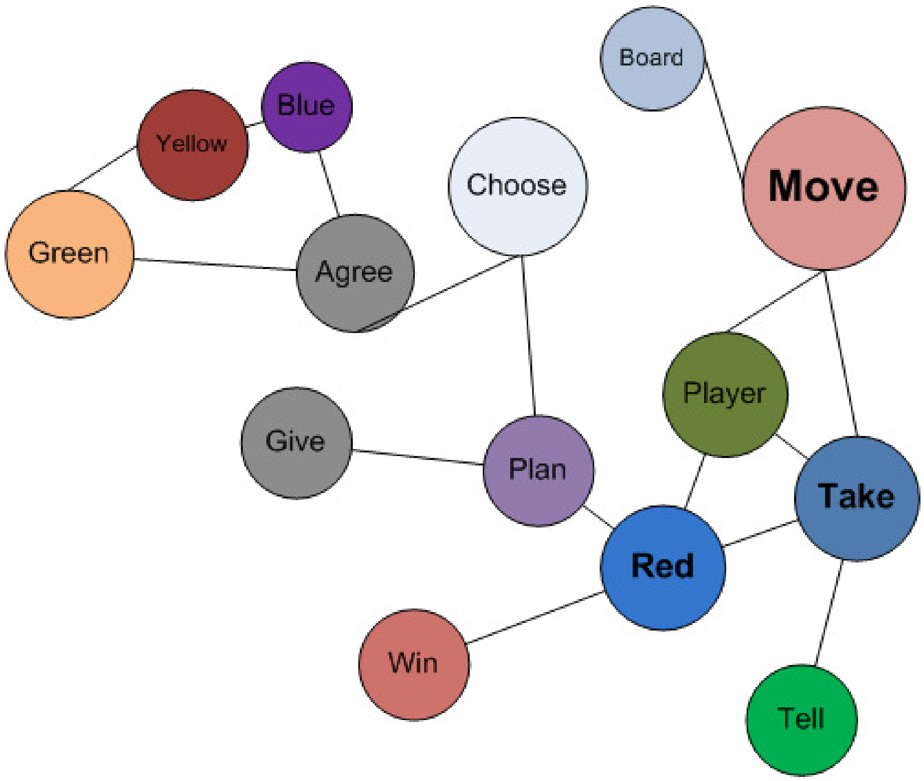


Figure 5.5 Predicted concept map for the "static game"

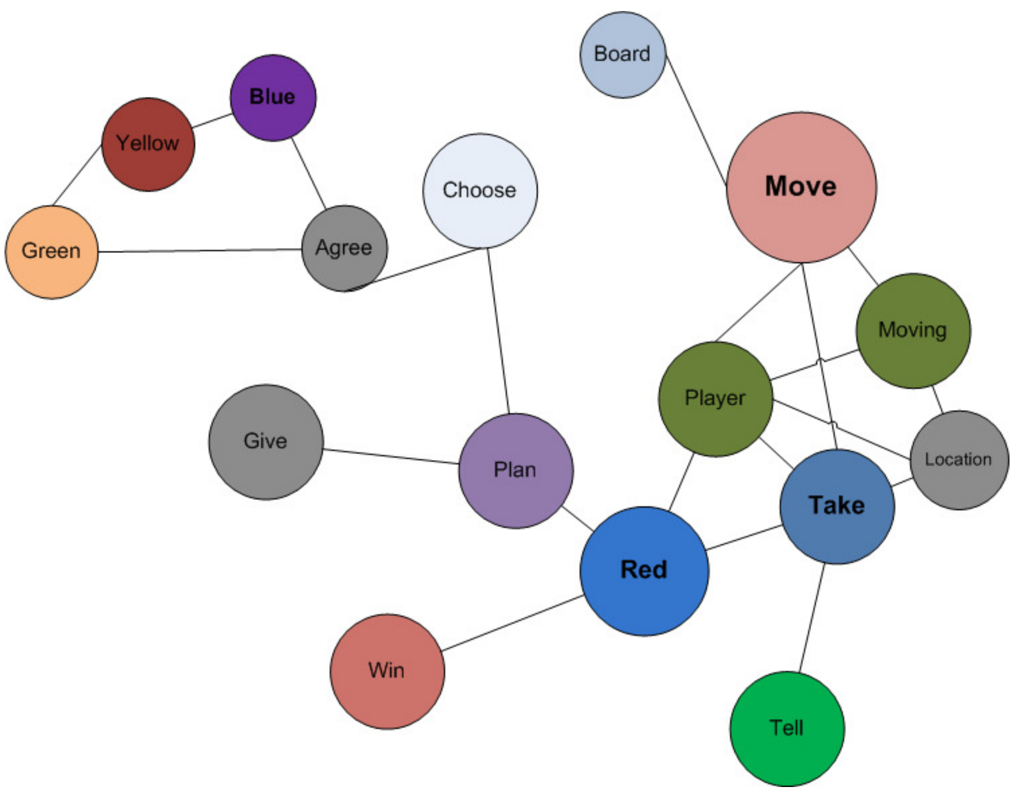


Figure 5.6 Predicted concept map for the "moving game"

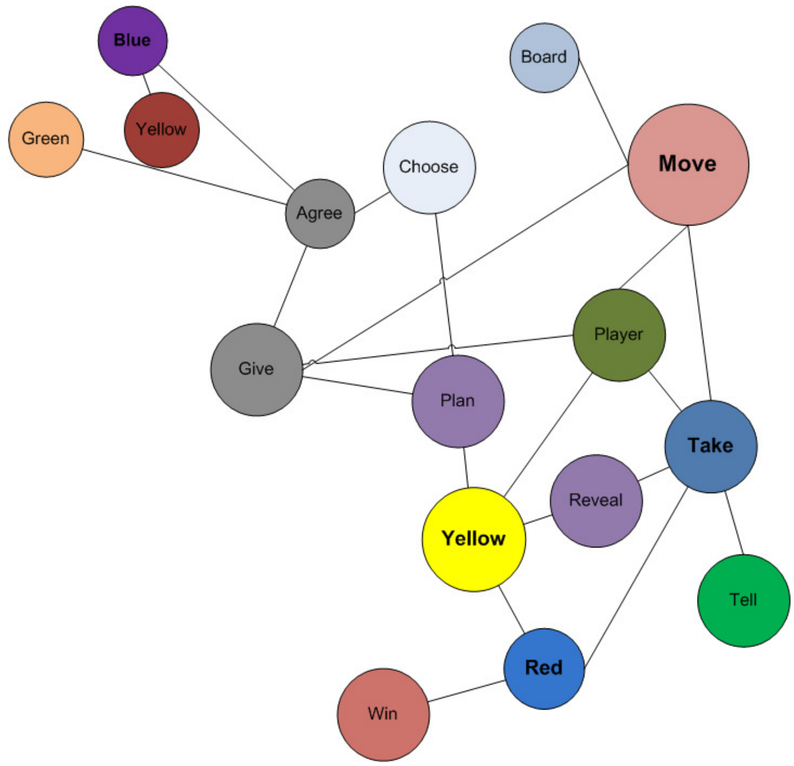


Figure 5.7 Predicted concept map for the "static and disguised game"

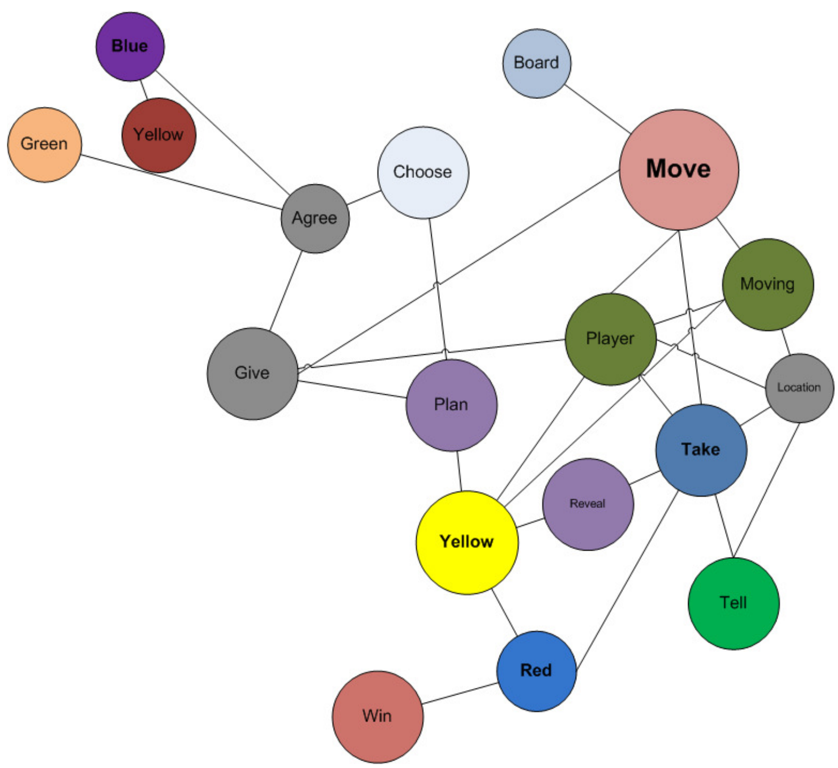


Figure 5.8 Predicted concept map for the "moving and disguised game"

The hit rates calculated for the communication logs and CDM were subjected to tests of statistical significance. As the data was not normally distributed non-parametric tests of statistical significance were performed. The Mann-Whitney U rank sum test was applied as a between-group comparison to reveal differences between the two measures. Effect sizes were calculated for the Mann-Whitney U test statistic. Cohen (1988) described the importance of reporting the effect size (ES) statistic for empirical results so as to assist in the understanding of the power of the test applied. Field (2009, p57) give the values for effect sizes as:

Table 5.2 Effect size

Effect size (ES)	Category
ES=0.10	Small effect
ES=0.30	Medium effect
ES=0.50	Large effect

5.2.6 Procedure

Before participants arrived for the experiment the administration of game conditions were set according to a counter-balancing schedule and all computers were turned on with relevant software programs initiated. Participants were greeted on arrival and allowed to choose their own work station. A brief introduction was given to the participants and questions taken and answered. The game rules and the requirement that all communication had to occur through MSN were explained and informed consent obtained. All game tasks were limited to eight minutes, as controlled by the alarm function on a stopwatch. Games were started on the setting of the stopwatch and a simultaneous prompt by the experimenter. The CDM was administered at the end of each game. Once the experiment was completed participants were debriefed, thanked for their time and effort and asked to sign a form to acknowledge receipt of the £10.

The two raters were instructed in the two parts of the inter-rater study they were taking part in and provided with the material needed to conduct the first and second part of the inter-rater reliability exercise.

5.3 Results

5.3.1 Inter-rater reliability findings

Table 5.3 shows the results of the average percentage agreement comparison made between the raters and Leximancer™ in terms of the words extracted from the selection of CDM and the MSN transcripts. Table 5.4 shows the average percentage agreement between the analyst and the two coders with regards to the words extracted from the data transcripts.

Table 5.3 Average percentage agreement between the analyst, coder 1and coder 2 extracted words compared to Leximancer™

Average % agreement with Leximancer™	
Analyst	89.91%
Coder 1	89.88%
Coder 2	86.87%

Table 5.4 Average percentage agreement between analyst, coder 1 and coder 2

	Coder 1	Coder 2
Analyst	88%	89%
Coder 1		85%

Table 5.5 shows the average percentage agreement between analyst, coder 1 and coder 2 on the categorisation of concepts for the data processed for each of the two data collection methods (e.g. CDM and MSN).

Table 5.5 Average percentage agreement between analyst, coder 1 and coder 2 on the categorisation of concepts

% agreement on CDM			% agreement on MSN		
	Coder 1	Coder 2		Coder 1	Coder 2
Analyst	90.00%	97.50%	Analyst	87.50%	95.00%
Coder 1		87.50%	Coder 1		80.00%

The percentage agreement achieved for both the words extracted and the categorisation of relevant concepts is higher than the required 80% meaning that the findings reported here were reliable and consistent with the coding framework presented in Table 5.1. The results of the Kendall tau-b test of proportion of agreement of the ratings can be seen in Table 5.6 below. Statistically significant levels of high agreement were found.

Table 5.6 Results of Kendall's tau-b test of correlation between ratings

	Analyst compared to Coder 1		Analyst compared to Coder 2		Coder 1 compared to Coder 2	
	Kendall's tau b statistic	P-value	Kendall's tau b statistic	P-value	Kendall's tau b statistic	P-value
CDM	0.967	P<0.001	0.976	P<0.001	0.967	P<0.001
MSN	0.931	P<0.001	0.991	P<0.001	0.938	P<0.001

5.3.2 Validity findings

Table 5.7 shows the hit rate ratios calculated for the communication logs, whilst Table 5.8 shows the hit rates calculated for the CDM.

Table 5.7 Results of the hit rate calculation for the communication logs

	Static Game	Moving Game	Static and Disguised Game	Moving and Disguised Game	Mean by Team
Team 1	0.64	0.56	0.80	0.70	0.67
Team 2	0.57	0.56	0.66	0.76	0.64
Team 3	0.50	0.62	0.80	0.82	0.68
Team 4	0.64	0.56	0.60	0.82	0.65
Team 5	0.50	0.50	0.73	0.64	0.59
Mean by game	0.57	0.56	0.72	0.75	

Table 5.8 Results of the hit rate calculation for the CDM

	Static Game	Moving Game	Static and Disguised Game	Moving and Disguised Game	Mean by Team
Team 1	0.64	0.64	0.60	0.70	0.64
Team 2	0.28	0.28	0.73	0.76	0.51
Team 3	0.28	0.28	0.53	0.82	0.47
Team 4	0.21	0.21	0.53	0.76	0.42
Team 5	0.42	0.42	0.46	0.64	0.48
Mean by game	0.36	0.36	0.57	0.74	

A statistically significant difference was found between the communication logs and the CDM (U=123.00, $P<0.05$) with a medium effect size (ES= 0.46). Average hit rate found for the communication logs was 0.70 whilst it was 0.54 for the CDM. Higher mean hit rate was also found for the communication logs, compared to the CDM, across the teams and all four game types. The communication logs therefore achieved the highest ratio of observed to predicted concepts compared to the CDM.

5.4 Discussion

Distributed SA has been found to enable comparison of systems (Patrick et al., 2006; Stanton et al., 2009a). This means that the results of Distributed SA assessments can be used to inform technological support and organisational design, for instance, to decide between types of systems to utilise in particular contexts (such as military command and control, control room operations or civil first response systems). Accurate assessment of Distributed SA is therefore of importance to the Human Factors community (Patrick et al., 2006; Stanton et al., 2008; Salmon et al., 2008). This chapter aimed to consider the inter-rater reliability of network analysis, a method applied to assess and model Distributed SA, and the validity of two data collection methods used to inform the network analysis method. An experimental study was developed to allow Distributed SA data to be collected using two techniques (e.g. the communication logs and the CDMs). Recent software tools have been developed to assist in the analysis of textual data, one of these, the Leximancer™, was also subjected to tests of inter-rater reliability.

Network analysis has been shown to be a useful means of assessing and representing Distributed SA. It has been pointed out that SA is strongly related to information and network analysis assesses information which has been activated through the interaction between human and technological agents (Artman, 2000; Gorman et al., 2006; Nofi, 2000; Patrick et al., 2006; Stanton et al., 2009a; Salmon et al., 2009b). Network analysis can therefore reveal the emergent property of Distributed SA (Stanton et al., 2009a). It is this quality which enables a comparison between systems, as advocated by Stanton et al. (2009a) and Patrick and Morgan (2010). By considering the extent to which a system is able to exchange information, for a particular task to be successfully accomplished, it becomes possible to assess whether technological or organisational design changes need to be made. It is also possible to consider whether one system is better than another in particular circumstances (e.g. particular task contexts or particular environments) (Patrick and Morgan, 2010; Artman, 2000). This has long been a topic of great interest in the military domain where the structure of C2 teams are considered for optimal fit between task and external environments (Alberts and Hayes, 2006; Sorensen and Stanton, 2011; Stanton et al., 2008). The method is not without limitations, however, as it is associated with limitations common for all types of qualitative research, such as subjectivity, lack of generalisability and reliability (Annett, 2002a; Annett, 2002b). Additionally, qualitative methods are time and resource intensive (Houghton et al., 2006). These limitations reduce the accessibility of the measure and constrains the potential application of the findings (Houghton et al., 2006). As such, software tools have been developed to assist in network analysis, particularly with regards to reducing the time involved in analysis, increasing the amount of data which can be assessed and increasing the objectivity of the qualitative analysis (Gretch et al., 2002; Smith and Humphreys, 2006). The benefit of such software programs is the standardisation of the coding process through the application of algorithms. This ensures that all data is treated in the same manner which, in turn, increases the reliability of the method.

The study presented here considered the reliability of the network analysis method by subjecting two stages of analysis to inter-rater reliability tests. The first part of analysis compared the words extracted by three human analysts against the words extracted by Leximancer™; this tested the software tools inter-rater reliability. When considering the results high levels of inter-rater reliability were found which is consistent with similar findings reported elsewhere (Gretch et al., 2002; Walker et al., 2011). A higher percentage agreement was found between the words extracted by Leximancer™ and the analyst and two coders than between the analyst and the two coders, which indicate a greater degree of variability between the human analysts than between the human and the machine. This first part of the analysis is particularly demanding in terms of the time taken to extract words. This means that without software support significant constraints are placed on the amount of raw data which can, realistically, be included in analysis. Automating the process of treating the raw data it is conceivable that one could go from only being able to analyse, for instance, a sample of 5 teams (of say 100) to considering the entire population in the same amount of time. The support of the Leximancer™ tool therefore seem to counter the constraints highlighted by Houghton et al. (2006) as associated with time and resource intensive analysis.

The second part of the inter-rater reliability analysis found that there was a high average percentage agreement between the analyst and coders in terms of the categorisation of concepts. The percentage agreement was higher than the required 80% level (Jentsch and Bowers, 2005; Green et al., 2012; Bysari et al., 2011). When considering the individual data collection methods the same high level of agreement, i.e. above 80%, was found. The statistically significant results found for the Kendall tau-b test of proportion of agreement between the ratings supports this finding. This means that the findings reported here were reliable and consistent with the coding framework. These findings also indicate that the network analysis method provide a method which minimise disagreement between independent observers, a key characteristic, highlighted by Annett (2002a), as a marker of a sound method.

Stanton and Young (1999a) pointed out, however, that a method may be reliable and produce the same results over time and yet not be valid. In other words the method may be reliable but be measuring something entirely different from what is assumed to be measured (Stanton and Young, 2003). This chapter therefore sought to consider the validity of two data collection techniques which feed into the network analysis method. This was done by considering the concepts from the data against predicted concepts developed from the HTA's of each game. A hit rate was calculated which showed that the communication logs achieved a higher score on all tasks compared to the CDM, despite some variation between the five teams. A statistical significance difference between the two measures hit rates was found, showing that the communication logs achieved higher hit rates compared to the CDM. This finding was also supported by the means calculated by game and team. It was showed that the communication logs achieved the highest average hit rate across all teams and all games when compared to the CDM. This finding was somewhat surprising because the CDM is an information elicitation technique (Klein and Armstrong, 2005) and has been used to elicit Distributed SA with success elsewhere (Sorensen and Stanton, 2011). Nevertheless, it would appear that the retrospective data collection which is afforded by the CDM does not achieve the same level of validity as the communication logs. The communication logs therefore appear to be generalising somewhat better to the situation (Stanton et al., 2008), which it stands as a record of, when compared to the CDM which provides a retrospective account of the same situation.

These early, but promising, findings support the use of network analysis techniques for the assessment of Distributed SA and the utilisation of Leximancer™ as a tool to automate the analysis process.

5.5 Conclusion

The use of any method requires that the levels of reliability and validity associated with the findings are high. Without reliability or validity the findings cannot be utilised in any way and the method's usefulness is severely constrained. This chapter has presented a study in which the inter-rater reliability of a network analysis method, i.e. concept maps, was tested. Tests were also performed to consider the validity of two data collection techniques which feed into the network analysis method. These methods require a significant time and resource investment as the analysis process requires a high level of researcher input. To alleviate these weaknesses software tools have been developed, such as Leximancer™, which automates the extraction of words into codes and concept maps. The reliability of the analysis produced by these software tools, must, just like the analysis provided by the human analyst, be high. The inter-rater reliability study presented here therefore subjected both the Leximancer tool and the concept map methodology to tests of inter-rater reliability. High levels of inter-rater reliability were found for the words extracted by Leximancer when compared against the analyst and two additional coders. High levels of inter-rater reliability were also found between the analyst and the two coders when comparing their ratings of the concepts in the concept maps against the predicted concept maps developed from the HTA. These findings support the results presented elsewhere which have shown that Leximancer performs as well as human analysts when analysing and producing concept maps. Leximancer can therefore be applied as a reliable tool in network analysis. The findings also showed that network analysis, in the form of concept maps, are a reliable means of assessing and representing Distributed SA. When considering the validity of the data collection techniques communication logs were found to have higher levels of validity compared to the CDM, this means that the communication logs provided a more accurate reflection of the situation it recorded.

With the aid of software tools, such as Leximancer, the application of network analysis to assess Distributed SA gains increased accessibility and therefore has the potential for wider use in the Human Factors community. Given what is known of the benefits to system and technological design in utilising Distributed SA as a means of comparing different systems these findings are of significance to both researcher and practitioners.

Chapter 4 highlighted the importance of considering the time at which data is collected from team activity (e.g. before, during or after activity) and Chapter 5 has tested the validity and reliability of network analysis as a means of assessing the data collected to reveal Distributed SA in a team. Based on the findings from this chapter, communication data will be collected in future experimental work. Chapter 6 therefore utilises the network analysis method, with communication data collected from teams' discussions, to complete a series of experimental tasks. Furthermore, Chapter 4 raised the issue of SA breakdown as being of particular interest to the research community; Chapter 6 therefore seeks to address this issue by considering whether there is a relationship between Distributed SA and performance.

6 How Distributed SA is Mediated by Organisational Structure and Correlated with Task Success

6.1 Introduction

The research presented in the chapters of this thesis have so far considered which perspective of SA that holds the most promise for revealing the SA of teams. Having established the theory of Distributed SA as the approach that offers the most comprehensive intellectual framework for considering team SA, the methods that could be applied to assess the phenomenon was considered. The findings of the preceding chapters set the scene for a further exploration of the theory by subjecting the assumption that Distributed SA is associated with performance to an empirical test. This relationship is not well-established in the literature.

Team performance is an important contributor to system safety (Flin et al., 2002). While the use of teams may, in part, be due to the idea that "there is safety in numbers" the complexities of modern work environments are such that one individual operator is rarely able to operate safely on their own. As a consequence of the wider use of teams in high-risk and time-critical domains (Worm et al., 1998) the focus has shifted to teams' non-technical skills and their role in safe and efficient task performance (e.g. Fioratou et al., 2010; O'Connor and Flin, 2003). Such environments place significant demands on the team's ability to engage with and adapt dynamically to their environment. This ability has been described as SA and has been considered a part of safe operation in complex systems (Stanton et al., 2001b). This has been particularly true of safety in aviation (Stanton et al., 2001b) but has been increasingly acknowledged as an important part of safe team operations in areas such as emergency services, surgical teams, military C2 and nuclear power plant operations (e.g. Fioratou et al., 2010; Hazlehurst et al., 2007; Nofi, 2000; Patrick and Morgan, 2010; Worm et al., 1998).

As described in Chapter 4, C2 systems, or teams, are made up of human and technical agents utilised to achieve a common goal (Jenkins et al., 2009a). Stanton et al. (2006b) explained that SA therefore becomes an emergent property which arises from team member's interaction with each other and artefacts in the world.

Similarly, Nofi (2000) argued that communication plays a critical role in developing SA in teams, whilst (Orsanu, 1995) found that information exchange was linked with high levels of SA and that high levels of SA was linked with high levels of performance in teams, as has been found elsewhere (Cooke et al., 2009; Endsley, 2000).

Communication has therefore been identified as a key aspect of Distributed SA and it stands to reason that good communication fosters the emergence of sound Distributed SA and team performance. Communication is the transaction which allows awareness to be developed within a distributed team, and as a two-way processes, it proves vulnerable to team dynamics (Stanton et al., 2009a). Singleton (1989), for instance, suggested that inadequate team organisation may lead to poor communication. According to Stanton (1996) team communication become most effective when coordinating activities. Stanton (1996) asserted that coordination refers to formal structural aspects of the team; i.e. how tasks, responsibilities and lines of communication are assigned, or in other words, what sort of organisational structure the teams are governed by. The literature describes a number of studies which considers the characteristics of archetypical organisational structures in terms of optimal performance (Alberts and Hayes, 2003; Walker et al., 2009a). Furthermore, research has shown that organisational structure and operational procedures impact on task performance (Stammers and Hallam, 1985). In most complex human-technical systems, the current state of a system, a battlefield or plant, can only be perceived indirectly (Patrick and Morgan, 2010). Information is received through team members which introduces risks in that the potential for incomplete and inaccurate external representations of temporal and spatial elements of the situation (Patrick and Morgan, 2010; Stammers and Hallam, 1985). This is echoed by Masys (2005) who defined SA as a systemic attribute shaped by the sociotechnical systems' characteristics. Masys (2005) went on to say that:

> "SA is a fundamental concept in the operation of complex socio-technical systems" (p.548).

Despite the interest in team research Stewart and Barrick (2000) noted that "little is known about whether there is an optimal structure for teams" (p.144). The literature suggests, however, that variations in team performance may be explained by differences in team structure (Patrick and Morgan, 2010). Indeed, Patrick and Morgan (2010) asserted that the organisational structure of a team may have consequences for the distribution of SA, similarly, Masys (2005) pointed out that dysfunctional relations within a system can result in degradation of SA which often leads to dangerous or life-threatening consequences in safety-critical environments.

Early research into sociotechnical systems (Trist, 1981) and team work (McGrath, 1984) indicated that differences in tasks mediate a relationship between a team's inputs, their internal processes and their outcomes (Stewart and Barrick, 2000; Stanton and Ashleigh, 2000). Whilst considerable focus has been placed on the development of good SA increasingly the role of poorly developed SA has been given attention (Stanton et al, 2001b; Rafferty et al., 2012). Breakdowns in SA have, for instance, been attributed to incidences of fratricide in the military domain (Simmons, 2003; Bundy, 1994). Fratricide has been defined as:

> "unforeseen and unintentional death or injury to friendly personnel" (U.S. Army; cited in Rafferty et al., 2012, p. 21).

In other words, friendly personnel are mistaken for the enemy and are therefore engaged in battle. Bundy (1994) reported that inadequate C2 and poor communication were often present in situations leading up to fratricide incidents. SA breakdowns have also been ascribed to human error in aviation (Endsley, 1995). Likewise, Salas et al. (2004) analysed an oil rig explosion on the Piper Alpha and concluded that failures in leadership, communication and SA delayed the execution of safety measures which resulted in a large number of casualties. They, further, described a case study in which the American Airlines Flight 965 crashed on the 20th of December 1995, (referred to the air accident investigation report) stating that a breakdown in communication and lack of SA were key contributing factors in the incident. Similar conclusions have also been drawn with regards to human error in the medical domain. For instance, Leonard et al. (2004) highlighted the important role of communication, through on-going dialogue, in maintaining SA. Fioratou et al. (2010) reported similar results, when they described a patient fatality arising from a failure of the medical team to interact to develop Distributed SA. They concluded that good SA emerges from the bidirectional process which takes place between seeking and giving information, or in the SA relevant transactions within the team, as was highlighted elsewhere by Salmon et al. (2010) among others (Stanton et al., 2006a). Indeed, Döös et al. (2004) argued that human error implies that something has gone wrong in the interaction between team members or the artefacts in their environment.

Evidently, some links have been established in the literature between the structure teams are organised into, their level of SA and performance (Endsley, 2000; Salmon et al., 2009b). However, as of yet, few studies have tested these assumptions experimentally to assert whether a relationship exists between team structure, performance and Distributed SA. Significant questions remain in particular with regards to the proposed link between Distributed SA and performance and between the impacts of organisational structure on Distributed SA through its established link with team task performance. The literature has therefore shown that a relationship exists between SA and performance and between organisational structures and performance.

Given the importance of organisational structure on teams, particularly in a C2 environment, it stands to reason that teams organised in different ways will exhibit different levels of SA as well as different levels of performance.

An experimental study was designed to investigate of the issues raised. For the purpose of this study experimental teams were modelled on C2 teams from the military domain. By selecting C2 teams, as a model for the experiment teams, it was also possible to configure the teams into five different organisational structures. This allowed for an investigation of organisational structures impact on performance and Distributed SA. The following hypotheses were developed and tested for the present study:

1. There will be significant differences between the five organisational structures in terms of performance.
2. Distributed SA will be positively correlated with performance
3. The relationship between performance and Distributed SA will be mediated by organisational structure

This chapter address these hypotheses and thereby contribute to the existing body of knowledge in this area. To this aim, a study was devised which sought to test whether task success rate (i.e. team performance) is related to the quality of the team discussions (i.e. Distributed SA). Furthermore, this chapter considers whether the organisational structure of teams has a moderating effect on the performance and Distributed SA observed. In the following section details of the method which were applied are given.

6.2 Method

6.2.1 Participants

A sample of 300 was drawn from the general student population of the University of Southampton. The inclusion criteria for participants were fluency in English and experience of using instant messaging software such as Skype™ or Microsoft Messenger™ (MSN). Permission to conduct the study was sought and granted by the University of Southampton Ethics Committee. Participants were recruited through an extensive poster and email advertisement campaign. Individual volunteers who met the inclusion criteria were randomly allocated to teams of five. A total of 60 teams were created.

6.2.2 Experimental design

A between-subjects design was used where the independent variable was organisational structure and the dependent variables were Distributed SA and performance.

The characteristics of archetype network structures have been described by a number of authors (Walker et al., 2009a; Walker et al., 2009d; Alberts and Hayes, 2003). Their work builds on early social network research by, notably, Bavelas (1948) and Leavitt (1951) who defined the 'Chain', 'Y', 'Circle', 'Wheel' structures. Later developments in the field have defined the 'All-connected' structure (e.g. Alberts and Hayes, 2003, Walker et al., 2009a). MSN was used to design the organisational structures by constraining communication patterns between the players, as illustrated in Figure 6.1. In each of the five organisational structures above player 1 was connected to the experimenter in MSN and was responsible for communicating team decisions.

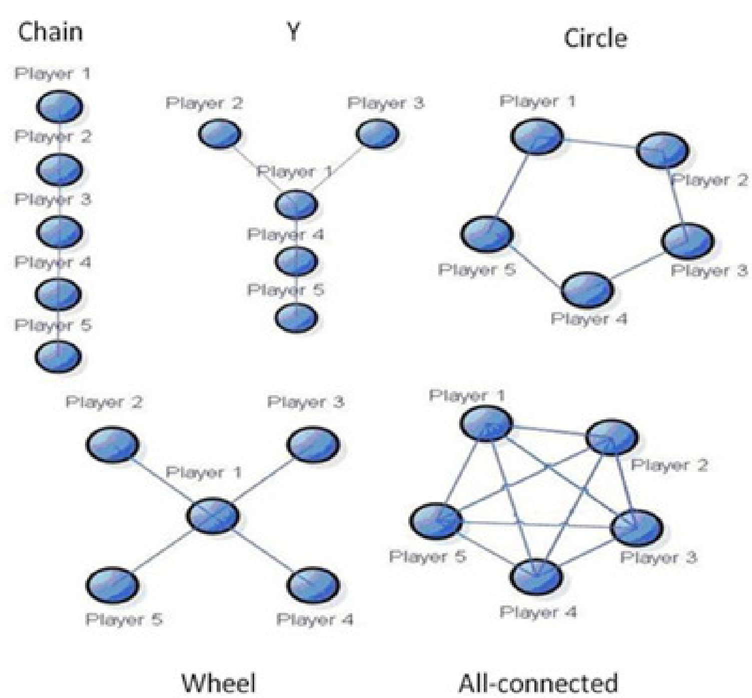


Figure 6.1 The five organisational structures configured using MSN

6.2.3 Experimental tasks

Building on the games presented in Chapter 5, a strategy game was developed in which a chess board was used with players of four different colours; blue, yellow, green and red. The blue players signified friendly players (controlled by the experimental team), yellow players were unknown, while green were neutral and red pieces were enemy or opponents pieces (Malone and Schapp, 2002). Each team consisted of five blue players, i.e. each team member controlled one blue player each; and the team collaborated to achieve the goals of the game. Collaboration was ensured through communication, for instance, team members could suggest moves to other team members. The team structure determined the pattern of communication which was allowed (as seen in Figure 6.1). For instance, in the Chain structure player 5, at the bottom of the chain, would pass on their desired more or suggestions of other team members moves to player 4 who would then pass the communication onto player 3, and so on until it reached player 1. In the Circle team Player 5 could pass their message on to both player 4 and player 1, and so on. The overall aim of any game was to take as many red players as possible. Taking a red was performed by removing a red player from the game. The rules of the game were the same as those given in Chapter 5 (see section 5.2.3).

Each team played four start positions twice, with eight games played in total. The start positions are given in Figure 6.2, Figure 6.3 Figure 6.4 and Figure 6.5. Firstly, In the start position seen in Figure 6.2 all players' colours were shown and the opponent players did not move. This game was therefore a "static" game variant.

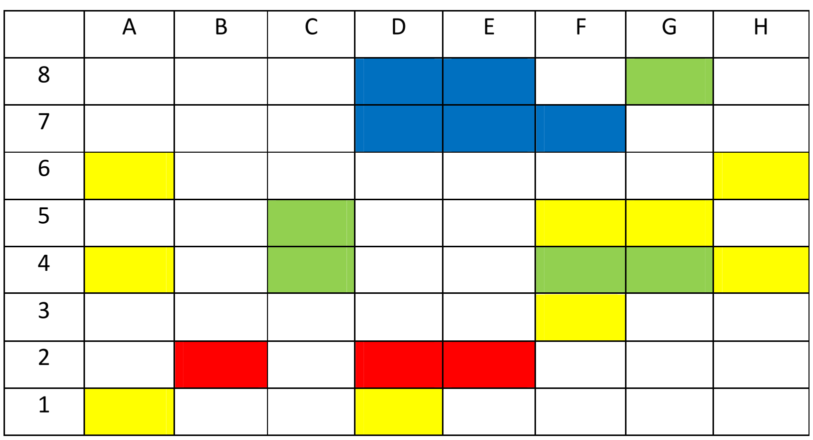
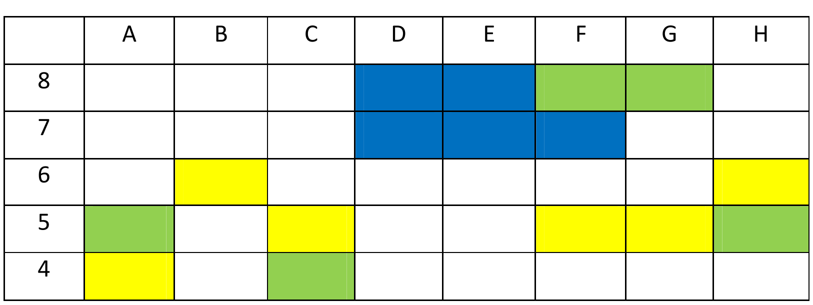


Figure 6.2 Static Game

Secondly, the start position seen in Figure 6.3 represented a dynamic game in which opponent players moved. In this instance, however, all players' colours were shown. This game was therefore a "moving" game variant.



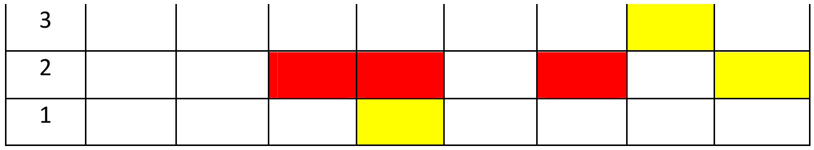


Figure 6.3 Moving Game

Thirdly, the start position seen in Figure 6.4 represented a game in which none of the opponent players moved. In this instance all players' colours were presented as yellow. This game was therefore a "static and disguised" game variant.

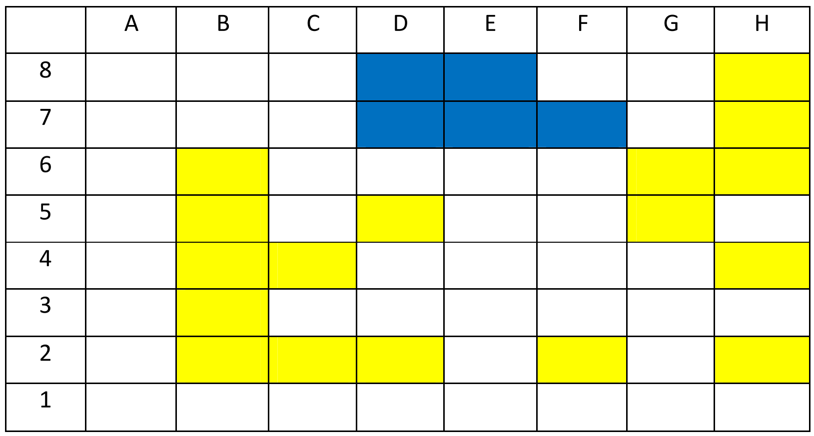


Figure 6.4 Static and Disguised Game

Finally, in the start position seen in Figure 6.5 all opponent players were shown as yellow and could move. This meant that red and green were disguised and blue players had to reveal the true colour of opponent players before identifying and possibly taking a red. This game was therefore a "moving and disguised" game variant.

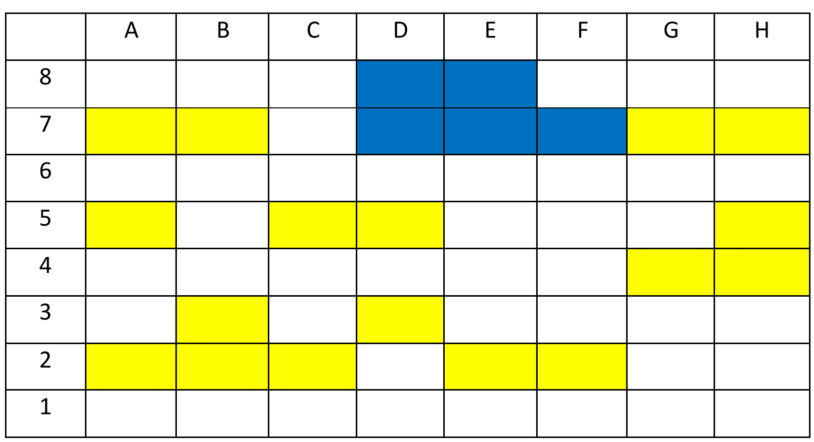


Figure 6.5 Moving and Disguised Game

The updated game was verified as a relevant abstraction of the main factors pertinent to command training by a retired British Colonel with operational and instructional experience. The game was also analogous with those used in military C2 training (Malone and Schapp, 2002).

6.2.4 Hardware, software and workstations

As described in Chapter 5, the experimenter used a standard laptop, monitor and keyboard to control the experiment. In the five individual cubicles five PC notebooks with monitors and keyboards were set up. Participants were provided with hearing protectors, to prevent distractions and to encourage immersion in the game. For an illustration of the experiment environment see Figure 5.3. A webcam was used to continuously stream a live video of the chess board from the experimenter's laptop and this was shared with participants using a virtual meeting hosting site. The participants were shown the webcam image in the left hand corner of their computer screens with the MSN window in the right hand corner, as shown in Figure 5.4. An html file was created which was retained as a record of moves made by players on the board and was a record of each team's performance.

6.2.5 Procedure

Participants were greeted on arrival and allowed to choose their own work station. A brief introduction was then given to the study and questions taken and answered. The game rules and the requirement that all communication had to occur through MSN were explained. Player one was informed of their role in passing on team decisions to the experimenter. Participants were asked to use the hearing protectors. Questions about the game rules were taken and answered. Informed consent was taken and participants directed to an online demographic survey before a five minute training trial was initiated. Once the experiment was completed participants were debriefed, thanked for their time and effort and asked to sign a form to acknowledge receipt of the £20.

6.2.6 Data reduction and analysis

Performance

Team performance scores were recorded in terms of the number of red players and non-red players which were taken in the games. These scores were summed for all teams on each of the eight tasks to give an overall score for each organisational structure. Stanton and Young (1999a) describe a procedure developed from signal-detection theory by which 'hit rates' was calculated. By considering the percentage of predictions, i.e. relevant concepts, and the false alarm ratio, i.e. irrelevant concepts, a single figure can be given which represents how accurate participant's predictions were. Table 6.1. illustrates the possible events from which hit rates can be calculated.

Table 6.1 The signal-detection paradigm

		Player classification	
		Red	**Non Red**
Action	**Taken**	*Hit*	*Fratricide*
	Not Taken	*Miss*	*Fratricide Opportunities*

Two ratios were calculated: the target rate (FA; i.e. calculation of the ratio of red players taken to non-red players taken) and the fratricide rate (FA; i.e. the ratio of non-red players taken to opportunities for fratricide). Young and Stanton (2005) explained that a hit rate of 0.5 indicates equal ratio. A hit rate greater than 0.5, e.g. for target rate for a given organisational structure, means that red players taken outnumber the non-red players taken. A hit rate of 1.0 would, for target rate, reflect that all of the red players were taken. Hit rate was calculated as hit divided by hit plus miss, whilst fratricide rate was calculated as fratricide events divided by fratricide opportunitites plus fratricide events.

Distributed SA

Leximancer™ was used to support a network analysis of the communication data from the teams whereby concept maps were developed. These concepts were in turn categorised as either relevant or not relevant. Table 6.2 shows the list of relevant concepts, any concepts contained in the concept maps not on this list were categorised as irrelevant.

Table 6.2 Categorisation framework of relevant concepts

Agree	Disguised	Irrelevant	Plan	Suggest
Ask	Donate	Kill	Player/Players	Surround
Blue	Eat	Legal	Quick/Quickly	Tactics
Board	Expose	Line	Red/Reds	Take
Bottom	Forfeit	Location	Repeat	Tell
Capture	Forward	Minutes	Reveal	Time
Choose	Game	Move/Moving	Round	Told
Colours	Give	Okay	Rules	Turn
Column	Go's/Goes	Opinion	Same	Win/Won/Winning
Confirm	Green	Opponents	Screen	Yellow
Coordinate	Hurry	Outnumber	Seconds	Yes
Copy	Illegal	Pass	Similar	
Decide	Inappropriate	Paste	Strategy	

Applying the same signal-detection procedure enabled a calculation of the Distributed Situational Relevance rate (DSR) for the ratio of relevant to irrelevant concepts a team displayed. DSR was calculated as relevant concepts divided by relevant concepts plus irrelevant concepts.

For DSR a hit rate of 0.5 indicates equal ratio of relevant and irrelevant concepts while a hit rate greater than 0.5 means that relevant concepts outnumber the irrelevant concepts. A hit rate of 1.0 reflects complete accuracy or that all concepts were relevant.

As discussed in Chapter 3, SNA can be performed to quantify diameter, density and the concept with the highest sociometric status of the organisational structures discussion.

The values calculated for distributed situational relevance, target rate and fratricide rate were subjected to Spearman's test of correlation to establish whether a positive correlation existed between them.

Inter-rater reliability

To establish the reliability of the categorisation of relevant words (as relevant or irrelevant), the data were subjected to qualitative inter-rater reliability tests whereby percentage agreement between individual coders are calculated and compared. The comparison was made in accordance with the guidance given by Marques and McCall (2005) and others (Jentsch and Bowers, 2005; Dockrell et al., 2012; Green et al., 2012; Bysari et al., 2011), as described in Chapter 5 (see section 5.1.2). Agreement of 80% or above between the raters and analyst was applied as the criteria to determine the reliability of the coding framework (Jentsch and Bowers, 2005; Dockrell et al., 2012; Green et al., 2012; Bysari et al., 2011).

The inter-rater reliability tests found 89% agreement in the classification of concepts as relevant between the analyst and coder 1, 92% agreement between the analyst and coder 2 and finally 75% agreement between coder 1 and coder 2, giving an average agreement of 88%. The high level of agreement indicate that the coding framework developed was applied consistently and reliably (Jentsch and Bowers, 2005).

6.3 Results

6.3.1 Demographics

The sample of 300 participants consisted of 54% males, 46% females with mean age of 21. 85% had English as their first language with the remaining 15% with English as fluent second language. All were proficient users of MSN.

6.3.2 Performance

Figure 6.6 shows the number of red taken, the number of red players missed and the number of non-red players taken (i.e. the instances of fratricide).

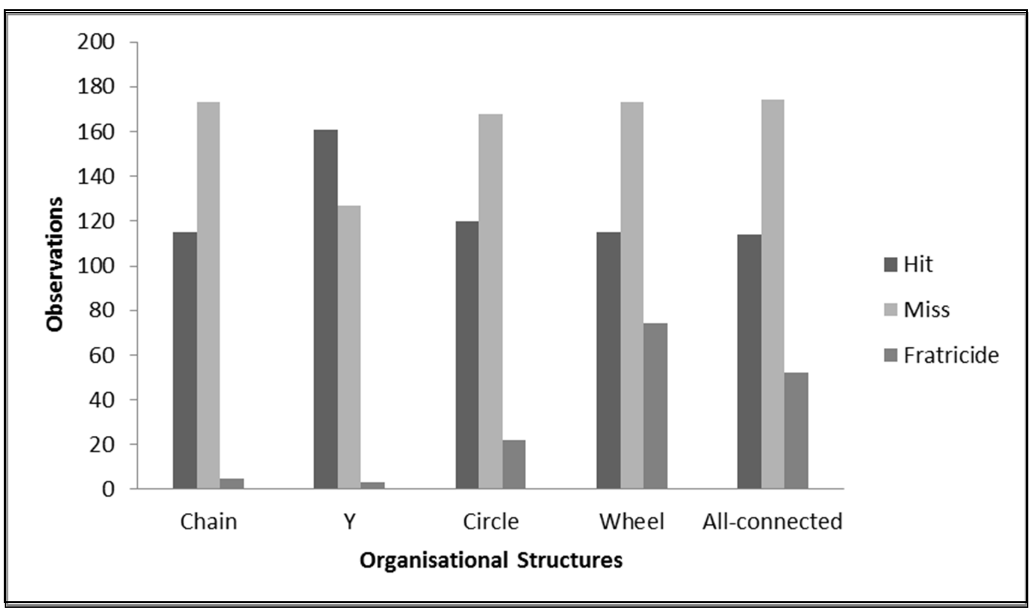


Figure 6.6 Number of red taken (hits), number of red missed (miss) and number of fratricide events

Figure 6.6 shows that the Y organisational structure took the highest number of red players, followed by the Circle organisational structure. Chain, Wheel and All-connected took the fewest number of red players. Furthermore, the table shows that the Y organisational structure followed by Chain and Circle took the least number of non-red players, whilst the Wheel and All-connected organisational structures took the highest number of non-red players. Furthermore, for the Y organisational structure took a higher number of red players taken than they missed red players. For all the other organisational structures there were a greater number of red players missed than taken.

Table 6.3 shows a summary of the fratricide opportunities encountered by each organisational structure and the target rate and fratricide rate calculated.

Table 6.3 Summary of fratricide opportunities and calculations for target rate and fratricide rate for each of the five organisational structures

	Fratricide Opportunities	Target Rate	Fratricide Rate
Chain	283	0.39	0.02
Y	285	0.56	0.01
Circle	266	0.41	0.07
Wheel	214	0.40	0.20
All-connected	236	0.39	0.15

The target rate achieved by Chain was 0.39 and the fratricide rate was 0.02, whilst for the Y organisational structure a target rate of 0.56 was achieved with a fratricide rate of 0.01. The target rate achieved by Circle was 0.41 and the fratricide rate was 0.07, for Wheel a target rate of 0.40 was found and a fratricide rate 0.20. Finally, the target rate achieved by All-connected was 0.39 and the fratricide rate was 0.15. The Wheel and All-connected therefore had considerably higher fratricide rates compared to the Chain, Y or Circle. These ratios reflect the findings presented in Figure 6.6 above.

6.3.3 Distributed SA

Figure 6.7 shows the total relevant and irrelevant concepts by organisational structure.

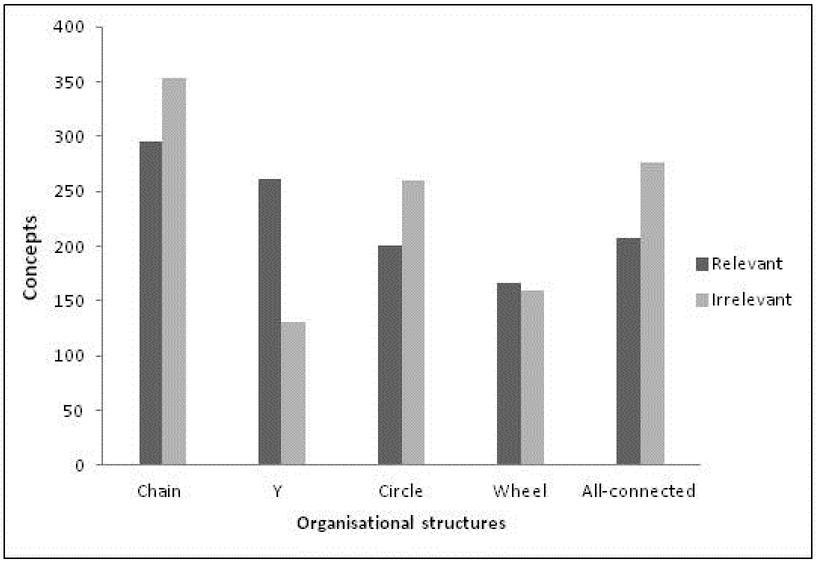


Figure 6.7 Relevant and irrelevant concepts by organisational structure

As can be seen from Figure 6.7, the Y organisational structure has a greater number of relevant concepts compared to irrelevant concepts, whilst the reverse was true for the Chain, Circle and All-connected organisational structures. The Wheel organisational structure had near equal numbers of relevant and irrelevant concepts.

Table 6.4 shows the SNA metrics calculated for the concept maps in terms of diameter, density, sociometric status and the concept with the highest sociometric status by organisational structure.

Table 6.4 SNA metrics by organisational structure

	Diameter	Density	Sociometric Status	Concept
Chain	5.00	0.03	0.33	"Moves"
Y	14.00	0.07	0.50	"Player"
Circle	14.00	0.05	0.47	"Player"
Wheel	8.00	0.06	0.50	"Take"
All-connected	13.00	0.05	0.32	"Yellow"

The results of the DSR calculation reflected these finding, see Figure 6.8below.

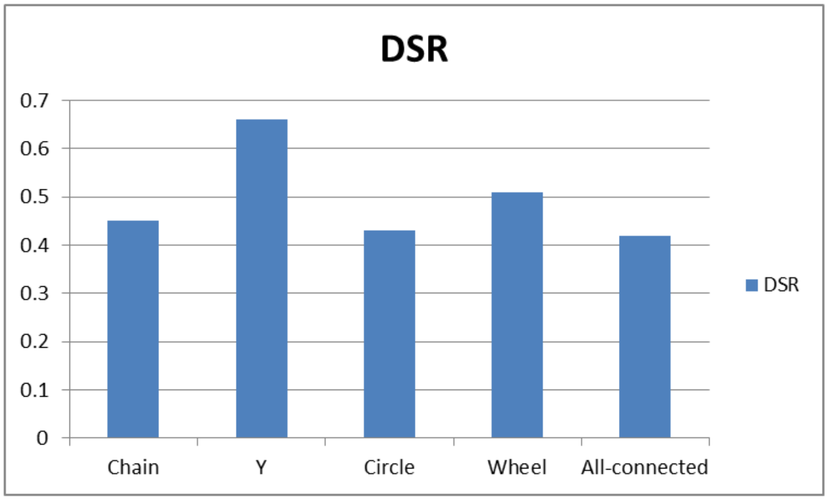


Figure 6.8 DSR ratio by organisational structure

The task success rate and fratricide rate were subjected to tests of correlation to establish whether they were correlated with DSR as reported below.

6.3.4 Correlations

A positive correlation was found between distributed situational relevance and target rate ($r=0.923$, $P<0.001$). The scatter plot shown in Figure 6.9 summarises the relationship. Overall, there was a strong positive correlation between distributed situational relevance and target rate. In other words, increases in the number of situationally relevant concepts are correlated with increases in target rate. The higher the distributed situationally relevant concepts the higher the ratio of red players taken to red players missed.

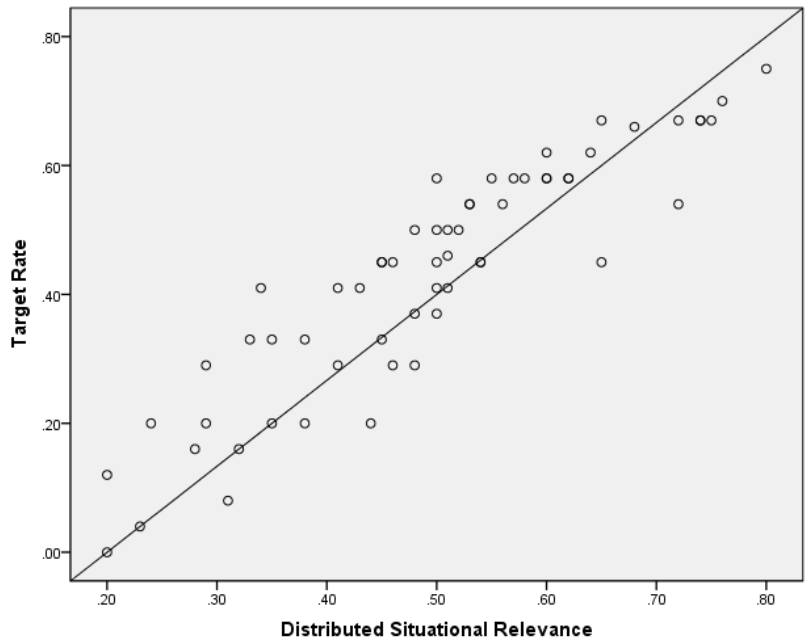


Figure 6.9 Scatter plot showing relationship between distributed situational relevance and target rate

A moderate negative correlation was observed for distributed situational relevance and fratricide rate (r=-0.520, P<0.01) as reflected in the scatter plot seen in Figure 6.10 below. In other words, decreases in the number of distributed situationally relevant concepts were correlated with increases in fratricide rate. Figure 6.6 reflects the pattern observed in figure 6.9 where two organisational structures, e.g. the Wheel and the All-connected, had higher fratricide rates compared to the Chain, Y and Cirlce structures who all had low fratricide rates.

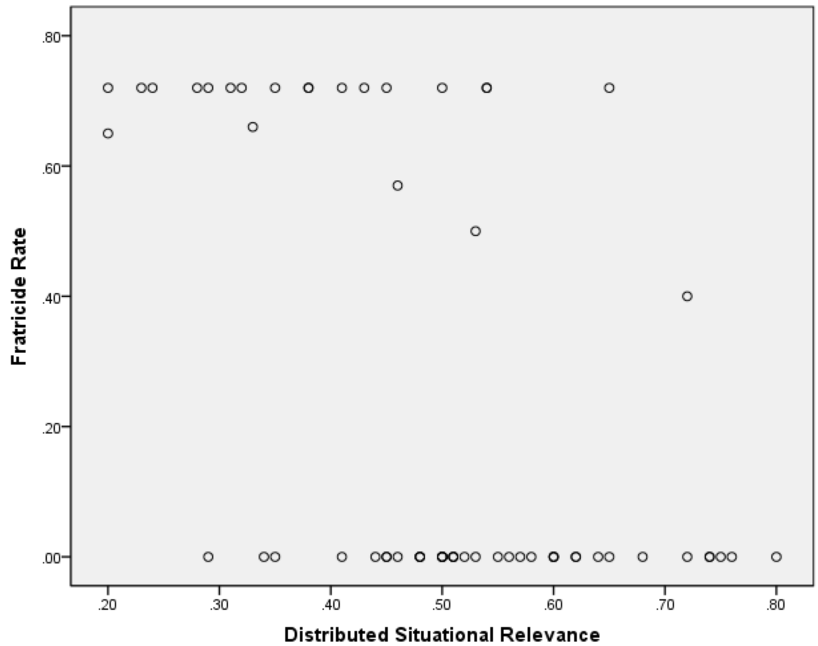


Figure 6.10 Scatter plot showing relationship between distributed situational relevance and fratricide rate

6.4 Discussion

This chapter has examined the relationship between organisational structure, performance and Distributed SA. Organisational structure did appear to have an effect upon team performance with discernible differences between the teams. It was clear that Y had the highest target rate compared to the other organisational structures. This means that Y took the highest number of red players whilst at the same time taking the least number of non-red players in error. Indeed, across the 12 teams only 3 non-red players were taken by Y. Furthermore, the lowest target rate was found for Wheel, closely followed by the All-connected organisational structure, with 74 and 52 non-red players taken, respectively. These findings lend support to the literature which has argued that a relationship exists between organisational structure and team performance (e.g. Salmon et al., 2009c; Salmon et al., 2009b; Endsley, 2000; Stammers and Hallam, 1985; Patrick and Morgan, 2010; Alberts and Hayes, 2003). Support was therefore found for hypothesis 1; performance does, in part, appear to be a function of organisational structure.

Considerable importance has been placed on teams' role in operating safety-critical processes (Worm et al., 1998) and questions have been asked with regards to whether there exists an optimal team structure. The findings presented here indicate that some organisational structures may be better placed than others to achieve effective performance, or indeed to mitigate significant errors from taking place. Stewart and Barrick (2000) pointed to a lack of research investigating optimal structure for teams. In light of the findings presented here, the Y organisation structure appears to be the most effective structure in terms of task performance and Distributed SA. Whilst the Y structure performed best in this experimental context, further work should be undertaken to explore the strengths and weaknesses of the four other organisational structures in other contexts. Indeed, optimal structure may be contingent on the nature of the tasks being performed as well as the conditions under which the teams are operating. The literature does suggest that not one single structure remains optimal for all conditions (Stewart and Barrick, 2000) and adaptation of the team structure during task performance may be required (Alberts and Hayes, 2003; Walker et al., 2009a; Walker et al., 2009d). Further research should therefore consider the nature of this relationship.

The differences found between the organisational structures indicated that the constraints placed on teams' coordinating activities, such as their lines of communication and ability to interact affected the way in which SA transactions could take place and consequently on the way in which Distributed SA emerged. It has been suggested that inadequate team organisation and poor communication leads to poor task performance (Singleton, 1989) and the same appears true of the quality of the Distributed SA. This supports Masys' (2005) claim concerning the fundamental role of SA in complex sociotechnical systems. Distributed SA quality ought therefore to be evaluated through considering the quality of SA transactions taking place in the team (Salmon et al., 2009b). In so doing, support can be provided to ensure that the team organisation does not hinder successful information exchange within teams so that sound Distributed SA may emerge. Patrick and Morgan (2010) pointed to the fractured nature of information in distributed systems where the state of a system can only be perceived indirectly, and indeed can only be collated through information exchange by collaborative agents and the risks associated with such information dependency. Focusing on SA transactions as a means of identifying, and mitigating, the potential for SA breakdown in teams therefore holds particular promise for the safety community. SA transactions will be explored further in Chapter 7.

When considering Distributed SA in terms of the relevant team discussions, differences between the organisational structures were evident. For instance, whilst the highest numbers of concepts were observed for the All-connected organisational structure this organisational structure had the lowest level of relevant concepts, as was evident in the low distributed situational relevance ratio. The low level of relevant concepts was also seen in the low network density this organisational structure displayed.

Whilst many of the same concepts appeared across the five organisational structures, the way in which the concepts were interlinked appeared to be different. The activation of information, or concepts, pertains to the most critical aspect of Distributed SA (e.g. Stanton et al., 2006a; Salmon et al., 2009b). This can be seen in the comparison of the Y and Circle network's diameter and density. Both networks have the same diameter (14.00), and therefore have the opportunity to create the same number of links between concepts, but Y achieves a higher density compared to Circle. This may indicate that Y activated more of the inherent knowledge contained in the system than Circle did. The difference therefore appears to be arising from the difference in organisational structure, leading to different performance between Circle and Y and to different representations of Distributed SA. As a result of the difference in activation of knowledge it is conceivable that the most important concept for the organisational structure would differ also. Considering the data on sociometric status this was found to be the case for all but two of the organisational structures. Different emphasis had therefore been placed on different elements of the information available to the organisational structures. Interestingly, this may explain why the concept with the highest sociometric status was 'take' for the Wheel organisational structure who took the lowest number of red players whilst taking the highest number of non-red players, effectively the opposite of the game rules for the action "take". Clearly, it is not enough to have access to information; it must also be used by the right team members at the right time to be effective. The high number of fratricide events (i.e. non-red players taken) in the Wheel and All-connected organisational structures may therefore be due to ineffective activation of knowledge within teams, in line with the role ascribed to SA transactions as underpinning the emergence of Distributed SA (Stanton et al., 2006a; Salmon et al., 2010). The findings presented here therefore found support for hypothesis 2 and 3.

Given these findings it appears that teams may benefit from working in more than one organisational structure, as the utilisation of different structures may benefit from a "tailoring" to specific contexts. Team training should therefore be developed to enable teams to take a flexible approach to the performance of tasks. In relation to Distributed SA the findings indicated that teams should also focus on the quality of their communications. In particular, as a means by which they can increase the activation of knowledge at a system level and to improve task performance. This may in turn lead to fewer incidents of SA breakdown in teams working in high paced and complex environments.

The findings presented here showed a strong positive relationship between distributed situational relevance of the concepts developed from team discussions and target rate.

The higher the number of relevant concepts the higher the number of red players were taken. Task performance was therefore positively correlated with more relevant communications.

Based on the literature concerning the importance of Distributed SA and fratricide, it could also be expected that there would be a negative relationship between distributed situational relevance and fratricide rate (i.e. that where few situationally relevant concepts were would correlate with higher numbers of non-red players taken). The results showed a medium negative correlation between distributed situational relevance and fratricide rate when considering the combined data for all organisational structures. Inspecting the correlation between distributed situational relevance and fratricide rate by organisational structure, however, revealed that for the Circle, Wheel and All-connected organisational structures a strong, negative, correlation was found, (no statistically significant results were found for the other organisational structures). The strength of this relationship, however, is probably affected by the low frequency of non-red taken events. The association between poor performance and Distributed SA was also apparent when considering the total relevant concepts and number of fratricide incidents (i.e. non-red players taken) which showed that a high number of relevant concepts and a lower fratricide rate coexisted (as seen in the Y organisational structure), whilst at the same time a low number of relevant concepts appeared to co-occur with a higher fratricide rate (as seen in the Wheel organisational structure). The assumption that performance and Distributed SA are interlinked has therefore been shown here.

6.5 Conclusion

This study has shown that a relationship exists between performance and Distributed SA, as has been suggested elsewhere (e.g. Salas et al., 2004; Leonard et al., 2004; Endsley, 1995). More importantly, these promising findings have shown that the relationship between performance and Distributed SA appear to be mediated by organisational structure. This chapter has highlighted the importance of the interactions which take place within the teams, the SA transactions, as the means by which teams achieve and maintain Distributed SA. Analysing SA transactions to understand and mitigate SA breakdown in team and to design technology and systems to support transactions remains a neglected but promising area of Human Factors research. Light can only be shed on this important aspect of Distributed SA, however, if the early studies on transactional SA are supported by further exploratory work and it was to this research Chapter 7 aimed to contribute to.

7 Transactional SA in Teams: the Glue which holds Teams Together

7.1 Introduction

Chapter 6 showed that a relationship, mediated by organisational structure, appeared to exist between Distributed SA and performance. In order to understand this relationship it is important to explore how Distributed SA emerges in teams. In order to do this the components of the theory of Distributed SA, transactional SA and compatible SA, were examined. This chapter therefore seeks to shed light on the role of transactional and compatible SA in teams.

A critical success factor for any kind of team is the extent to which it can coordinate behaviour and communicate to complete a task (Patel et al., 2012). Chapter 6 showed that Distributed SA functions as an important contributor in successful team performance; however, much remains unclear in terms of how this relationship functions. Indeed, the factors which impact on the functioning of teams and, consequently, team performance, are areas which demand further examination. These issues therefore remain of continued interest to the Human Factors community. This chapter sets out to explore, in more detail, the interactions that take place within teams which have performed well and compare these to teams that have performed less well. The Distributed SA approach view team SA as an entity that is separate from team members (Salmon et al., 2008). In this perspective SA is a characteristic of the system itself (Artman and Garbis, 1998; Salmon et al., 2008). Salmon et al. (2008) explain that:

> "Distributed SA approaches assume that collaborative systems possess cognitive properties (such as SA) that are not part of individual cognition" (p.312).

Similarly, Artman and Garbis (1998) suggested that team performance in complex systems require a focus on the team as a system. SA is not only distributed across the agents who make up the team but also in the artefacts that they utilise (Artman and Garbis, 1998). Distributed SA, therefore, draws on the theory of distributed cognition (Hutchins, 1995a; Hutchins, 1995b). Hollan et al. (2000) state:

> "Distributed cognition extends the reach of what is considered cognitive beyond the individual to encompass interactions between people and with resources and materials in the environment" (p.175).

They argued that one can expect to find systems dynamically configuring themselves to bring subsystems into coordination to accomplish different functions. Distributed cognition is the shared awareness of goals, plans and details that one single team member can hold individually (Nemeth et al., 2004).

As highlighted in Chapter 3, the focus for measurement, when taking a distributed cognition or Distributed SA approach, is the interactions between human and non-human agents (e.g. Stanton et al., 2010a; Salmon et al., 2009a; Salmon et al., 2009b; Salmon et al., 2009c; Sorensen and Stanton, 2011) . Patel et al. (2012) asserted that:

> "collaboration involves two or more people engaged in interaction with each other [and] working towards a common goal" (p.1).

Through interacting with fellow team members an agent can improve their SA or improve the SA of others (Stanton et al., 2006a; Salmon et al., 2009b). SA is seen as the glue which binds the system, or team, together (Salmon et al., 2008). The interaction between agents, both human and non-human, is therefore vital to maintain the Distributed SA of the team (Salmon et al., 2008).

The nature of team performance, with team members holding different roles means each team member views and uses information differently to the other team members (Stanton et al., 2009a). This means it is not necessary for everyone in the team to be aware of the exactly the same information. It is more important to ensure that the appropriate information is communicated to the right team member at the right time (Gorman et al., 2006; Stanton et al., 2009c). Bowers et al. (1996) asserted that the interdependent characteristic of communication indicates that one team members task output becomes a critical input factor for another team member's task. This is compatible with Stanton et al. (2009d) who asserted that:

> "system theoretic principles… [where]… the transaction between system elements implies some sort of conversion of the information received, meaning that information elements will undergo change when they are used by a new part of the system" (p.486).

This issue of information conversion is explored further in this chapter.

7.1.1 Communication in teams as a means of coordinating teamwork

Communication was defined by Hoben (1954) as:

> "the verbal interchange of a thought or idea" (p5)

Whilst (Cartier, 1959) defined communication as occurring when:

> “a source transmits a message to a receiver with conscious intent to affect the latter’s behaviour” (p. 9).

Communication, therefore, forms an important part of teamwork. Communicative acts ensure that the required information is passed on to the right team member at the right time. Communication can therefore function as one form of SA transaction (Sorensen et al., 2011; Stanton et al., 2009c). Fioratou et al. (2010), among others (e.g. Stanton et al., 2006a; Salmon et al., 2008; Salmon et al., 2009b) took a systems approach to teams in that they argued that the unit of analysis of medical teams should be not just a single agent and their thoughts but the interaction between agents and their environments. They explained that a system can have cognitive properties that differ from those of the individuals who make up the system and that only the interactions between all components of the system can give an adequate picture of the SA within it (Fioratou et al., 2010). Fioratou et al. (2010) reported a medical case study of a fatality in which the medical team appears to have lost awareness of all relevant information sources about the patient’s condition. Communication between the members of the team also appeared to be less than optimal. For instance, equipment was laid out by one team member, as a prompt to use for another team member but the prompt was not recognised, or understood, and was therefore not acted on (Fioratou et al., 2010). Information from displays and other sources (such as the patient’s vital signs) were not passed on to the team members who could have utilised the information at significant points in time during the care of the patient (Fioratou et al., 2010). Though no one team member was at fault the case highlighted the key role that communication has in the development and maintenance of Distributed SA. This is supported by Rafferty et al. (2010) who found, in the study of fratricide, that adequate communication can prevent errors, whilst inadequate communication can cause errors. Effective communication has therefore been linked to effective SA (Stout et al., 1999; Rafferty et al., 2010; Stanton et al., 2010a; Salmon et al., 2009b).

Flin et al (1996) described a study of emergency response teams offshore in Emergency Command Centre's (ECC) led by an Offshore Installation Manager (OIM). During interviews with OIM's Flin et al. (1996) found that communication formed a crucial part of the successful execution of the emergency response tasks. Interestingly, they observed that what appeared necessary was to identify the players which required a "big picture" and support their maintenance of the big picture. For the ECC team overall it was more important that they knew who possessed the information they required, as and when they required it, rather than attempting to give all team members equal amounts of information. By taking a distributed cognition approach, such as applied by Flin et al. (1996) it is clear that the focus of any enquiry should be on the interactions between team members and the artefacts they utilise.

More recently, Hazlehurst et al. (2007) reported a study where a surgical teams activity was coordinated by communications (e.g. transactions), both verbal and non-verbal, in order to achieve coordinated activity. The surgical team worked together on separate but interdependent tasks to perform the surgery in a safe and effective manner (Hazlehurst et al., 2007). Hazlehurst et al. (2007) argued that SA:

> "is a consequence of this coordinated activity" (p.540).

By taking a distributed cognition perspective to the study of complex human behaviour in sociotechnical systems Hazlehurst et al. (2007) found that system behaviour, or team performance, emerged as a result of coordinated operation. In order to coordinate itself the team utilised information in different media, such as verbal communications, displays, textual or non-verbal communications (Hazlehurst et al., 2007). Hazlehurst et al. (2007)'s study described how the surgical team with its high division of labour had access to discrete areas of information about the patient who underwent surgery. Successful execution of the administration of different elements of the complex surgical procedure, at the exact time it was wanted, required an effective integration of all the information available to the different members of the surgical team (Hazlehurst et al., 2007). In the following the role of transactional SA in teamwork is considered.

7.1.2 The role of transactional SA in teamwork

Stanton et al. (2009c) explained that an SA transaction is an exchange of information which updates each team member's awareness in different ways. The emergence of Distributed SA occurs when parts of the system, such as team members, exchange information relevant to the situation. Stanton et al. (2006) described these communication acts as transactional SA, whilst Salmon et al. (2010) presented transactional SA as the process by which Distributed SA is acquired and maintained. They explained that a transaction represents an SA exchange between team members. For instance, the exchange of information in the team leads to transactions of awareness being passed around the team (Salmon et al., 2010). As such:

> "it is the systemic transformation of situational elements as they cross the system boundary from one team member to another that bestows upon team SA an emergent behaviour" (Salmon et al., 2010, p.6).

Stanton et al. (2009c), further, stated that there are points where the SA of individual team members are compatible during performance of tasks and it is at these points where transactions of SA between team members can occur. Team members engage in information exchanges as they perform tasks. Such exchanges can take the form of ‘requests’, ‘orders’ or ‘situation reports’ for instance (Stanton et al., 2009c). Such a categorisation of types of communication is in line with much other work which has considered communication types and counted the number of these (e.g. Costley et al., 1989; Kanki and Palmer, 1993; Urban et al., 1995). These exchanges:

> "tells the recipient what the sender is aware of" (Stanton et al., 2009c, p.52).

The information received, however, will be utilised according to the requirements of the recipient (Stanton et al., 2009c). Stanton et al. (2009c) further argued that by taking a distributed approach to the study of SA in teams it is possible to consider coordinated activity, which is the focus of this chapter.

By interacting with fellow team members an agent can improve their SA or improve the SA of others (Stanton et al., 2006a). The interaction between agents, both human and non-human, is therefore vital to maintain the Distributed SA of the team (Salmon et al., 2008). Wegner (1986) described that:

> "agents in collaborative systems can enhance each other’s awareness through SA transactions" (p. 316).

A transaction then represents an exchange of SA relevant information from one agent to another, including non-human agents (Salmon et al., 2008). Wegner (1986) went on to describe how:

> "a systems transactive memory, in terms of knowledge of who knows what in the system, allows them to engage in SA transactions in order to give or receive information required for SA" (p.316).

Information shared by individuals are, through interactions within the system or team, negotiated and manipulated through externalised construction of problem formulations or decisions (Mitchell and Nicholas, 2006). This process relies on the existence of information but also, and perhaps more importantly, the ability to access it (Mitchell and Nicholas, 2006). In order for team members to interact successfully and to extract information, they require, in the course of task performance, knowledge of 'who knows what' (Mitchell and Nicholas, 2006). This pertains to the notion of transactive memory. Transactive memory has been defined as:

> "a team's understanding of who has access to what specialised information within the team" (Mitchell and Nicholas, 2006, p.69).

Groups with high transactive memory have been argued as having a good understanding of information available through team members and that this is related to the facilitation of access to information and coordination of efforts towards a common goal (Yoo and Kanawattanachai, 2001; Mitchell and Nicholas, 2006; Wegner, 1986). Hollan et al. (2000) argued that:

> "memory involves a rich interaction between internal processes, the manipulation of objects, and the traffic in representations among [agents]" (p.176).

Yoo and Kanawattanachi (2001) presented a study in which they found that early communications were particularly important in teams as they allowed team members to build a transactive memory system. High volumes of communications were in this respect influencing the development of the transactive memory of the team. This transactive memory is then drawn upon to allow team members to coordinate their actions and knowledge to best perform their tasks (Moreland et al., 1996; Yoo and Kanawattanachai, 2001).

This means that, in contrast to the notion of team SA as shared which is promoted by Endsley (1995), team members do not need to know everything that other team members know (Salmon et al., 2008). Rather, team members can be aware of only that which they require to fulfil their interdependent tasks in the team.

Stanton et al. (2006) argued that it is the interactions between individuals and their environment in a system which leads to the emergence of Distributed SA. This claim is supported by an ever-growing body of research (e.g. Salmon et al., 2008; Salmon et al., 2009a; Salmon et al., 2009b; Salmon et al., 2009c; Salmon et al., 2010; Stanton et al., 2009c; Stanton et al., 2009d, Sorensen et al., 2011; Sorensen and Stanton, 2011; Sorensen and Stanton, in press; Flin et al., 2002; Fioratou, 2010). It is therefore important to explore the nature of these interactions, or SA transactions, as they aid the emergence of Distributed SA in teams and support teamwork. This chapter reports a case study in which the transactions of SA of teams which are known to have either performed more effectively, or to have performed less effectively, on the experimental tasks, are explored.

By considering the interactions between team members, in terms of communicative acts, this study seeks to answer the following research questions:

1. Are higher frequencies of communication found in more effective (e.g. high performing) teams compared to less effective (e.g. poorly performing) teams (Flin et al., 2002; Fioratou et al., 2010; Stout et al., 1999; Rafferty et al., 2010; Stanton et al., 2010a; Salmon et al., 2009b)?

2. Will teams who perform well have a higher number of transactions compared to less effective teams (Stanton et al., 2009c; Stanton et al., 2009d; Yoo and Kanawattanachi, 2001)?

3. Does only one, or do more team members, receive high sociometric status in the teams and does this pattern differ between more effective and less effective teams (Walker et al., 2011; Walker et al., 2009a; Walker et al., 2009d; Houghton et al., 2006)?

4. Can transactional SA be categorised into different taxonomic types (Stanton et al., 2009c; Stanton et al., 2009d; Costley et al., 1989; Kanki and Palmer, 1993; Urban et al., 1995)?

5. Does the type of transactional SA observed differ during the course of team performance (Stanton et al., 2009c; Stanton et al., 2009d)?

The case study selected to explore the research questions set out above is described in the following section.

7.2 Method

7.2.1 Participants

A subsample of 60 participants was taken from the larger sample of 300 described in Chapter 6. The lager sample was drawn from the general student population of the University of Southampton and contained the following inclusion criteria: fluency in English and experience of using instant messaging software such as Skype™ or Microsoft Messenger™(MSN). Volunteers who met the inclusion criteria were randomly allocated to teams of five. For the purpose of this case study twelve teams were selected.

7.2.2 Experimental design

A between-subjects design was used where the independent variable was team performance (e.g. more effective and less effective performance) and the dependent variable was communication and transactions. As described in Chapter 6, MSN was used as the medium through which the teams could communicate. The use of MSN, furthermore, enabled control of communication and true interdependency in team performance could be ensured (e.g. that all team members were required to complete the task).

7.2.3 Experimental tasks

The twelve teams performed eight experimental tasks of a strategy game, as described in Chapter 6 (see section 6.2.3).

7.2.4 Selection of case study

Chapter 6 described two performance criteria which were recorded for each team, namely, the number of red players and non-red players taken in any game. For the purpose of the current case study only the number of red players taken was considered of interest and this performance metric was used to inform the selection of the twelve teams. Based on the findings of the overall performance of all teams from the larger sample twelve teams were identified, six of which performed well (more effective teams, i.e. those that took more red players) and six which performed poorly (less effective teams, i.e. those that took fewer red players).

7.2.5 Hardware, software and workstations

The experiment environment and equipment was as described in Chapter 6 (see section 6.2.4). The MSN program was used to record the communications between team members.

7.2.6 Procedure

As described in Chapter 6 (see section 6.2.5), participants were given a brief introduction to the study on arrival and questions were taken and answered. The requirement that all communication takes place within the MSN program was explained, as was the game rules before questions were taken and answered. On completion of the experiment the participants were debriefed, thanked for their time and given £20 to cover travel expenses.

7.2.7 Data reduction and analysis

The analysis progressed in two phases; by firstly, considering quantitative team differences in the content and type of communication observed in the data; and secondly, by considering qualitative differences of the communications, as described below.

Team differences

The teams were sorted into two groups; those that were more effective and those that were less effective. The more effective teams were those that took 13 or more red players, whereas the less effective teams were those that took 6 or fewer red players.

Firstly, the exploratory analysis sought to reveal whether there were key characteristics in the interaction between teams which performed well (e.g. took the highest number of red players) compared to teams which performed poorly (e.g. took the fewest red players). Higher frequency of communications in teams that were making joint decisions has been found to differentiate between more effective teams and less teams effective in terms of the decisions they made (Rafferty et al., 2012). The team communications were, therefore, considered in terms of the frequency of communications and the number of transactions observed in the communications. These were summed for each team.

The summed frequencies of communications and transactions were subjected to tests of statistical significance. As the data was not normally distributed non-parametric tests of statistical significance were performed. The Mann-Whitney U rank sum test were applied as a between-group comparison to reveal differences between the teams. Effect sizes were calculated for each of the Mann-Whitney U test statistics. Field (2009, p.57) gives the values for effect sizes as shown in Table 5.2 (see Chapter 5).

Task relevant communications (TRC) were operationalised using the three categories identified by Stanton et al. (2009c; 2009d): 'situation reports', 'requests' and 'orders'. A fourth category, 'miscellaneous', was added to cover transactions which were not directly aimed at completing the game. This categorisation framework is supported by similar work undertaken elsewhere (e.g. Costley et al., 1989; Kanki and Palmer, 1993; Urban et al., 1995). Non-parametric tests of statistical significance were performed as described above. The percentage of the total TRC which fell into either category was calculated.

A social network was constructed based on the communications between the team members. In general terms a social network is:

> "a set of entities and actors [...] who have some type of relationship to one another" (Driskell and Mullen, 2005, p.58).

Driskell and Mullen (2005) went on to explain that SNA represents:

> "a method for analysing relationships between social entities" (p.58).

A social network can be created by plotting who is communicating with whom, or what concepts are associated with which other concepts, in a matrix. Driskell and Mullen (2005) among others (e.g. Walker et al., 2009a; Walker et al., 2011; Rafferty et al., 2012) stated that when a social network has been created from the communications between team members a range of statistical measures can be derived using graph theory (Harary, 1994). For the purpose of discerning between the teams, which performed well (more effective teams) and the teams that did not perform as well (less effective teams), sociometric status was calculated. This metric was chosen to enable a consideration of the contribution made by agents in the network (see section 3.5.6.), meaning that a higher sociometric status reflects a larger contribution made to the flow of communications (Houghton et al., 2006). Sociometric status was summed for each player across all eight tasks and compared between the more effective and less effective teams.

7.2.8 Inter-rater reliability

As highlighted in Chapters 5, the reliability of a method is paramount to ensure that the results can be utilised in a meaningful manner. To this aim, the qualitative coding of the team's communications into the four categories (e.g. 'situation report', 'request', 'order' or 'miscellaneous') was subjected to a test of inter-rater reliability. A random selection of 10% of the communication data used in this chapter was given to three independent raters. The comparison was made in accordance with the guidance given by Marques and McCall (2005) and others (Jentsch and Bowers, 2005; Dockrell et al., 2012; Green et al., 2012; Bysari et al., 2011), as described in Chapter 5 (see section 5.1.2). The criteria for reliability was therefore agreement of 80%, or above, between the raters and analyst (Jentsch and Bowers, 2005; Dockrell et al., 2012; Green et al., 2012; Bysari et al., 2011).

Three independent raters were recruited and each was given a sample of the data which was categorised according to the four SA transactional categories. All three raters were female with a mean age of 28, and all were postgraduates with research training and experience. Average agreement found between raters and the analyst was 85%.

7.3 Results

7.3.1 Demographics

The sample of 60 participants consisted of 54% males, 46% females with a mean age of 22. 85% had English as their first language and the remaining 15% had English as a fluent second language. All were proficient MSN users.

7.3.2 Team differences

The findings for the dependent variables communication and TRC are presented here for the two types of teams.

Frequency of communications

Figure 7.1 shows the frequency of communication observed between team members in more effective and less effective teams.

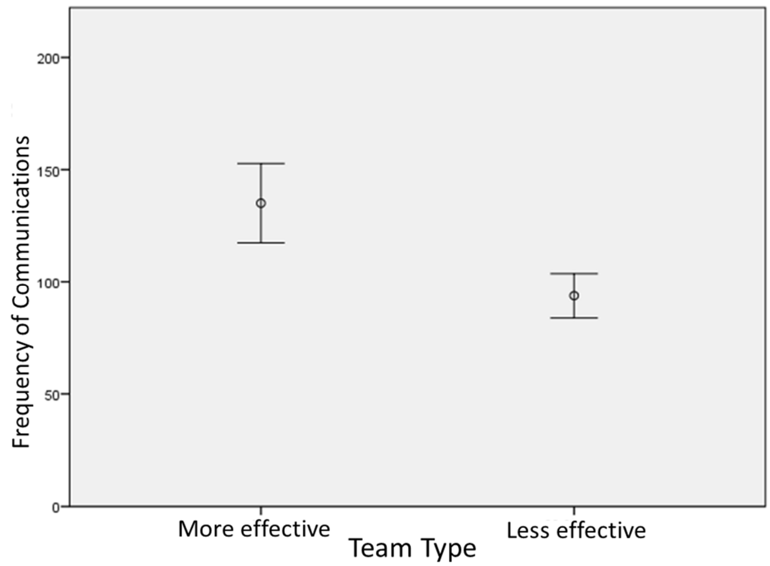


Figure 7.1 Error bar chart with 95% confidence interval, showing frequency of communication by team type

As can be seen in Figure 7.1, the more effective teams appeared to engage in more frequent communicative acts compared to the less effective teams. This apparent difference between the team types was subjected to tests of statistical significance.

The Mann-Whitney U test was used to compare frequency of communication between the more effective and less effective teams. A statistically significant difference was found between the more effective and less effective teams ($U=3.69$, $P<0.05$) with a medium effect size ($ES= 0.39$).This means that more effective teams had a significantly higher frequency of communications when compared to less effective teams.

Number of TRC

The transactions observed in the team communications were identified, as can be seen in Figure 7.2, which presents the number of transactions by team type.

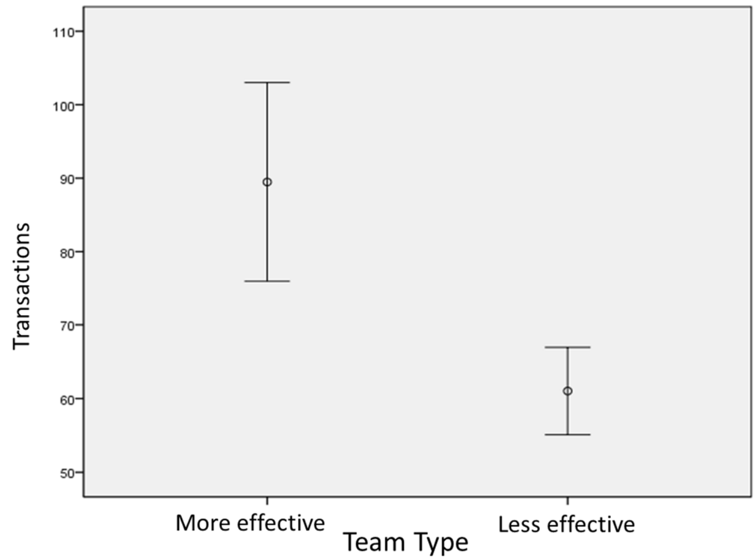


Figure 7.2. Error bar chart with 95% confidence interval, showing number of transactions by more effective and less effective teams

There appears to be a difference between the more effective and less effective teams in terms of the number of transactions found in these teams. Statistical tests were therefore applied to consider these apparent differences.

The Mann-Whitney U test was used to compare the number of transactions made between the two team types. A statistically significant difference was found between the more effective and less effective teams (U=619.00, P<0.001) with a medium effect size (ES=0.40). This means that more effective teams had a significantly higher number of transactions compared to less effective teams.

Categorisation of TRC

Figure 7.3 shows the mean number of 'situation reports', Figure 7.4 shows the mean number of 'requests', Figure 7.5 shows the mean number of 'orders' and, finally, Figure 7.6 shows the mean number of 'miscellaneous' transactions by team type. These figures show that there appears to be a difference in terms of the frequency with which the four categories of transactions were utilised in the two different team types. For the more effective teams 'situation reports' made up 57% of their total transactions (total of 2444 separate 'situation reports' were observed), 'requests' made up 22% of total transactions (total of 952 separate 'requests' were observed), 'orders' made up 18% (total of 785 separate 'orders' were observed), whilst 'miscellaneous' transactions only made up 3% of the more effective teams' total transactions (total of 114 separate 'miscellaneous' transactions were observed). In contrast, 'situation reports' made up

39% of the total transactions (total of 1140 separate ‘situation reports’ were observed), ‘requests’ made up 33% (total of 958 separate ‘requests’ were observed), ‘orders’ made up 15% of the total transactions (total of 442 separate ‘orders’ were observed), whilst ‘miscellaneous’ transactions made up 14% of the total transactions (total of 389 separate ‘miscellaneous’ transactions were observed) for the less effective team.

It is evident, therefore, that the more effective teams more often than the less effective teams utilised the three forms of transactions ‘situation reports’, ‘requests’ and ‘orders, whilst they less often engaged in ‘miscellaneous’ transactions.

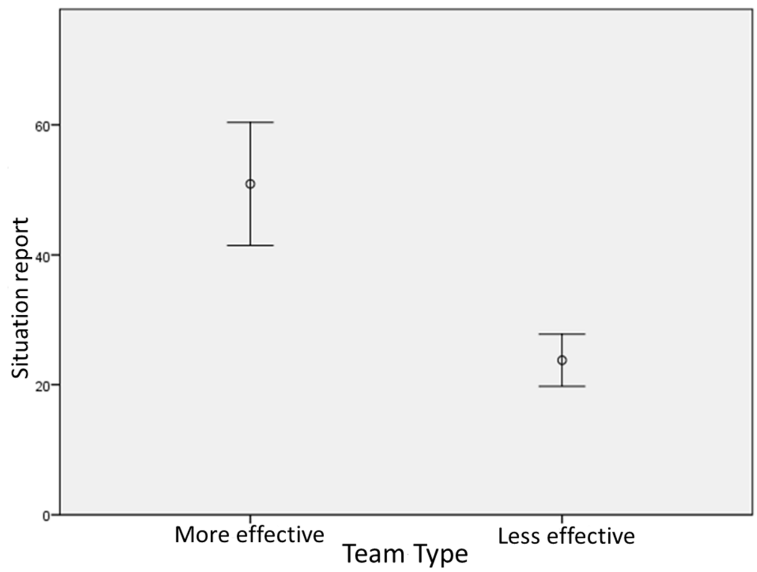


Figure 7.3. Error bar chart with 95% confidence interval, showing number of ‘situation report’ by more effective and less effective teams

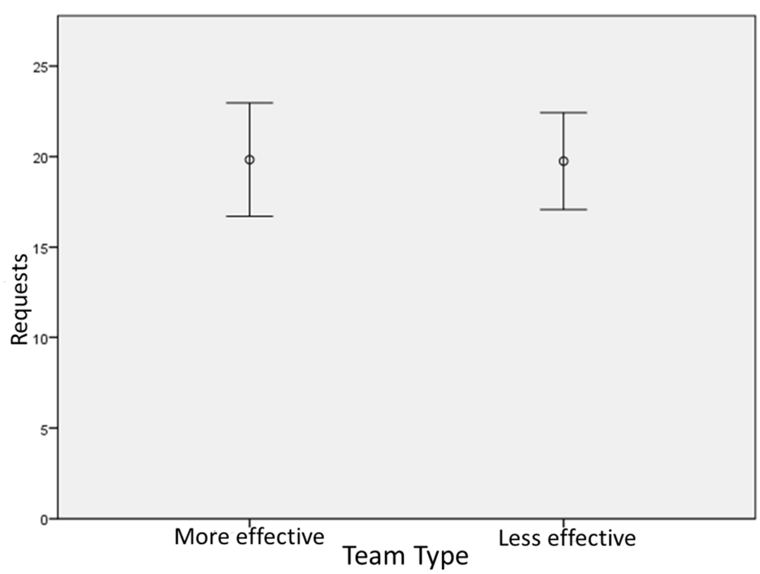


Figure 7.4. Error bar chart with 95% confidence interval, showing number of 'requests' by more effective and less effective teams

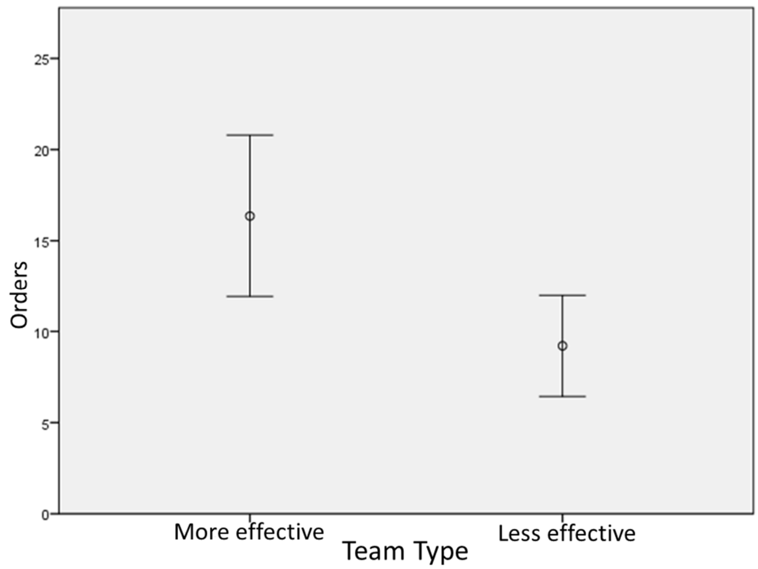


Figure 7.5. Error bar chart with 95% confidence interval, showing number of 'orders' by more effective and less effective teams

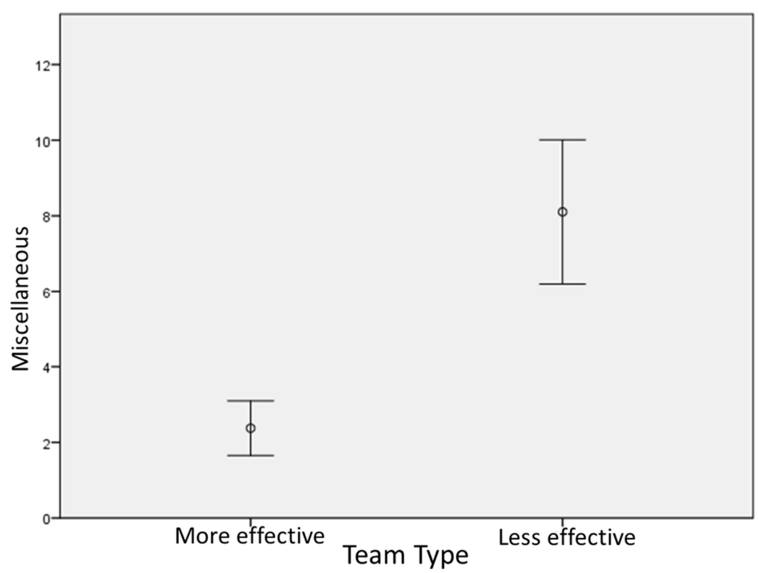


Figure 7.6. Error bar chart with 95% confidence interval, showing number of 'miscellaneous' transactions by more effective and less effective teams

Given the apparent differences between the more and less effective teams' utilisation of the four transactional taxonomic types statistical tests were applied to consider these.

The Mann-Whitney U test was used to compare the number of transactions made between the two team types. A statistically significant difference was found between the more effective and less effective teams on 'situation reports' ($U=475.00$, $P<0.001$) with a large effect size ($ES=0.51$). A statistically significant difference was also found between the more effective and less effective teams for 'orders' ($U=873.50$, $P<0.05$) with a small effect size ($ES=0.24$). A statically significant difference was, finally, found between more effective and less effective teams on 'miscellaneous' transactions ($U=438.50$, $P<0.001$) with a large effect size ($ES=0.54$). No statistically significant results were observed for 'requests' between the more effective and less effective teams ($U=1126.50$, P=N.S.)

As a means of qualitative exploration of the transactional taxonomic types, the occurrence of these were divided into; roughly, low, medium and high levels for the four categories across early, middle and late task performance. In the early stages of task performance it appeared that the more effective teams maintained a high level of 'situation reports' and 'requests' with medium levels of 'orders'. In contrast, the less effective teams display low levels of 'situation reports' paired with high levels of 'requests' and low levels of 'orders'. For the more effective teams 'miscellaneous' transactions remained low throughout task performance whilst it was high in the early and mid-point stages of task performance for the less effective teams and only dropped to medium levels in the late stage. In the mid-point of task performance the more effective teams display high levels of all transaction types, apart from the 'miscellaneous' category. For the less effective teams an increase in 'situation reports' was seen, with medium levels observed. 'Requests' remained high for this team type as does 'miscellaneous' transactions. Low levels of 'orders' were observed for the less effective team type. In the late stages of task performance the more effective teams maintained high levels of 'orders' but displayed a decrease in 'situation reports' and 'requests' to medium levels. In the less effective teams low levels of 'situation reports' were observed, with medium levels of 'requests', 'orders' and 'miscellaneous' transactions. The sociometric status calculated for the two team types are presented below.

Sociometric status

Figure 7.7 shows the sociometric status calculated from the frequency of communications for the more effective and less effective teams.

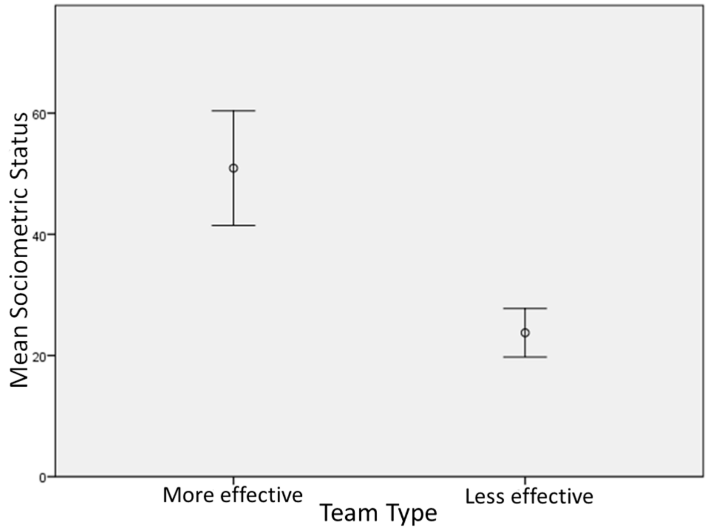


Figure 7.7. Error bar chart with 95% confidence interval, showing Sociometric status by team type

On visual exploration of Figure 7.7 it appears that there is a difference between the more effective and less effective teams in terms of sociometric status found in the team networks. Statistical tests were applied to establish whether these observed differences were statistically significant.

The Mann-Whitney U test was used to compare sociometric status of the team networks between the two team types. A statistically significant difference was foundnd between the more effective and less effective teams ($U=688.50$, $P<0.01$) with a medium effect size ($ES=0.35$). This means that more effective teams had a significantly higher sociometric status when compared to less effective teams.

Sociometric status was also considered by player to glean which players were more important in the teams.

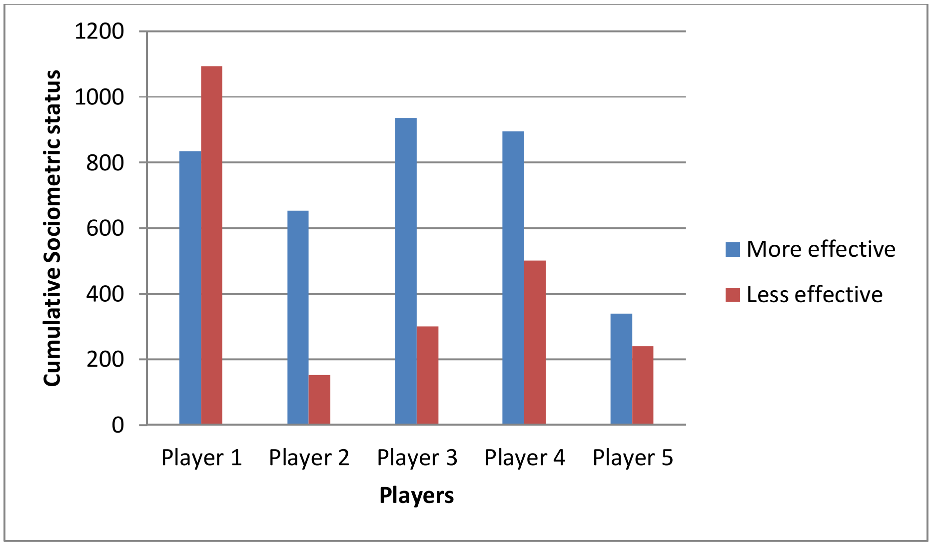


Figure 7.8 shows the sum of the sociometric status scores each player achieved in the twelve teams.

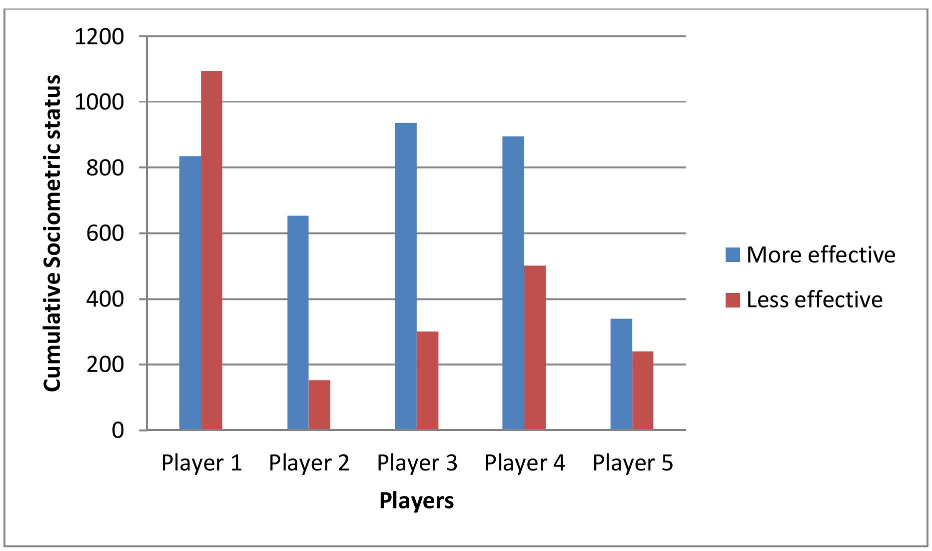


Figure 7.8. Sociometric status by player

It is clear from that all team members gained a higher sociometric status in the more effective teams compared to the less effective teams. Conversely, a disproportionately high sociometric status was observed for one of the players (i.e. player 1) in the less effective teams, with a 24% higher sociometric status achieved by the less effective teams. Greater difference can be seen between the more effective teams and less effective teams when considering the sociometric status for Player 2, Player 3 and Player 4 with 77%, 68% and 44% higher sociometric status observed in the more effective teams respectively. Little difference was found between Player 5's sociometric status for more effective compared to less effective teams with 29% higher sociometric status observed in the more effective teams. The less effective teams, therefore, appear to have had a more dominant Player 1, in terms of communication links as evident in how “busy” Player 1 appear to have been in these teams, compared to the more effective teams. The less effective teams therefore were the autocratic teams, with a centralised coordinator, whilst the more effective teams were organised in a more democratic manner.

7.4 Discussion

Teams are often utilised in complex environments and understanding the manner in which they interact and coordinate is therefore of importance to the research and practitioner communities (Patrick and Morgan, 2010). This thesis has argued that the manner in which the teams interact and share information to achieve task success is important to the understanding of the phenomenon of Distributed SA (Stanton et al., 2006a; Salmon et al., 2009b; Sorensen and Stanton, 2011). The very nature of teamwork means that team members have different roles (Stanton et al., 2009c; Walker et al., 2009c). As such, they combine information differently during task performance (Stanton et al., 2009c; Salmon et al., 2009b). It is through interactions with team members that an individual can improve their own SA and that of others (Stanton et al., 2009c; Salmon et al., 2009b). Transactional memory theory, however, has shown that in order to effectively access information in a team, the team members need to know who possesses the information they require (Wegner, 1986; Mitchell and Nicholas, 2006). Flow of information is therefore a necessary but not sufficient foundation for the development of SA. The right information must be accessed from the right person at the right time (Gorman et al., 2006; Stanton et al., 2009c). It is clear, as Salmon et al. (2008) argued that the interaction between agents is vital to maintain Distributed SA in teams. This chapter has therefore considered the nature of transactions in two team types and, in so doing, has sought to contribute to the understanding of how teams interact.

Five research questions were proposed at the outset of this chapter. The first and second question were related to assumed differences between the frequency of communications and the number of transactions which would be observed in more effective and less effective teams. The findings presented here showed that more effective teams had statistically significant higher frequency of communications and a higher number of transactions compared to less effective teams. The relationship between frequency of communication and team performance is unclear, with different studies reporting different relationships (Orsanu, 1990). Orsanu (1990) found that low performing teams increased communication in situations of high workload but that the communications in these instances were less effective compared to those seen in high performing teams. Rafferty et al. (2012) found a similar effect to that reported in this chapter, for within-team communications, however, an opposite effect was found between-teams. This study found that, for within teams, a high frequency of communication and a high number of transactions were related to more effective performance.

The third question pertained to assumed differences in sociometric status. Based on the patterns of communication, which was observed in the teams, matrixes of associations were constructed and sociometric status was calculated. The findings revealed that the more effective teams had a higher sociometric status compared to the less effective teams; these findings were shown to have statistical significance. This was explored further, by considering the sociometric status of the individual team members, and an interesting pattern emerged. All five team members gained a higher sociometric status in the more effective team compared to the less effective teams. This indicates that, in the more effective teams, all team members make greater contributions to the flow of communications within the team compared to the less effective team, where only one team member seemed to be making the greatest effort. Put simply the team members in the more effective team were "busier" than those in the less effective team (Walker et al., 2009a; Walker et al., 2009c; Walker et al., 2009d; Houghton et al., 2006) . The less effective team therefore appeared to have had an autocratic form with one dominant individual, i.e. Player 1. The more effective team, on the other hand, appears to have taken a democratic approach where most team members were sharing the burden of communication. It may be that having greater contributions from more team members enhances the team performance by encouraging greater sharing of SA relevant information. These team differences highlight that it is not merely the frequency of communications or the number of transactions which distinguish between team types. These differences were further considered using qualitative and quantitative means.

The information which each team activated and developed through task performance was explored. This was done in order to reveal whether the differences found between the team types were a result of differences in the manner in which transactions flowed within the teams. It has been argued throughout this thesis, and elsewhere, that such exploration can reveal the nature and quality of Distributed SA which has emerged in a team (Stanton et al., 2009c; Stanton et al., 2009d; Sorensen and Stanton, 2011; Sorensen and Stanton, in press).

The fourth research question asked whether transactional SA can be categorised into different types. These questions, and the issues described above, were sought explored and the transactions observed in the communication data categorised into one of the four SA transactional categories.

Urban et al. (1995) similarly found that effective teams appeared to be more efficient in their utilisation of questions and posedfewer questions whilst still receiving the necessary information, compared to less effective teams. This is reflected in the findings above, where a higher number of 'requests' were observed in the less effective team compared to the more effective team. Kraiger and Wenzel (1997) concluded that teams perform effectively when their communication is coordinated and contain little "chatter" and have concise questioning, feedback and confirmation.

The findings presented here supported these findings by showing that the less effective team had a higher number of ‘miscellaneous’ transactions compared to the more effective team.

The final question asked whether the type of transactional SA observed in the data differed during the course of task performance. It was clear from the data that a difference existed in the manner in which the different transaction categories were used throughout task performance. The more effective teams maintained high levels of ‘situation reports’ throughout the early and mid-part of task performance with high levels of ‘requests’ and medium levels of ‘orders. As task performance progresses, ‘orders’ were more often seen in the transactions as this category rose to high. In late task performance the levels of ‘situation report’ and ‘requests’ went down to medium whilst ‘order’ transactions increased to high.

In the less effective team there were low levels of ‘situation reports’ and ‘orders’ but high levels of ‘requests’ and ‘miscellaneous’ transactions in early task performance. In the mid-point of task performance ‘situation report’ transactions increased to medium whilst the other transaction categories remained at the same levels as early task performance. In late task performance ‘situation report’ decreased to low levels again, with a decrease also in ‘requests’ and ‘miscellaneous’ transactions from high to medium levels. ‘Orders’ on the other hand increased to medium levels.

The differences displayed between the teams seem to indicate that the more effective teams were better at spreading their ideas and transacting SA relevant information throughout the team compared to the less effective team. Transactions between system elements implies some sort of conversation of the information received, meaning that information elements will undergo some form of change when used by a new part of the system (Mitchell and Nicholas, 2006). Hollan et al. (2000) argued that distributed cognition concerns the bringing of subsystems into coordination to accomplish different functions.

As Flin et al. (1996) and Wegner (1986) reported, it is important for team members to know who holds what information. This may be the role of ‘situation reports’, in that these reveal to others what one team member knows of the current situation. ‘Requests’ may fulfil the same role, although in reverse, as by asking for information the sender may be provided with the requested information in the form of a 'situation report' or an 'order'. However, it is likely that in order for ‘requests’ to be effective they need to be directed at the right team member. In which case, a high continued presence of ‘situation reports’ may be a necessary prerequisite for effective team interactions and performance. If a team member doesn’t know what other team members may know they cannot ask the right question nor ask it of the right person. It may be that only when a high enough level of transactional memory has been established in the team that direct 'requests' are an efficient way of extracting information.

Stanton et al., (2009c; 2009d) state that information will be utilised according to the requirements of the recipient. Where the tasks performed are the same it should follow that the requirements of team members in more effective and less effective teams are similar. Despite this, differences were found between the team types. It may be that where the requirements of a team member is not yet know, neither to them nor fellow team members, a broader range of transaction types has a greater likelihood of meeting developing requirements. Indeed, it may be that by so doing they are forming the requirements for the individual team members as the game progresses. In other words, where team members do not know what they are supposed to be doing, a range of transactions across the three transaction categories 'situation report', 'request' and 'order' may guide them and support them in making sense of their role and the task they are performing. Yoo and Kanawattanachai (2001) presented a study in which high frequency of communications in early task performance was linked to the development of transactional memory in the team. Transactional memory in a team may therefore be a prerequisite of transactional SA as 'knowing who knows what' (Wegner, 1986) enables access to information and encourages the spread of information to those who need it (Flin et al., 2002). This may in part explain why the more effective teams, with a greater utilisation of the 'situation report' 'requests' and 'orders' throughout the task performance, did better compared to the less effective teams.

It has been argued that communication in teams are a means of coordinating teamwork (Stanton et al., 2009c; Sorensen and Stanton, 2012; Salmon et al., 2009b; Rafferty et al., 2011; Flin et al., 1996; Fioratou et al., 2010) and that team performance, in part, results from coordinated operation (Hazlehurst, 2007) between subcomponents of the team (Hollan et al., 2000). Hazlehurst (2007) argued that SA is a consequence of this coordinated activity. These findings support what has been argued elsewhere, in this thesis and by others, that the unit of analysis should not be a single agent but the interaction between agents and their environment (Stanton et al., 2006a; Stanton et al., 2009c; Salmon et al., 2009d; Salmon et al., 2008; Salmon et al., 2009b; Fioratou et al., 2010; Flin et al., 1996; Sorensen et al., 2011; Sorensen and Stanton, 2011; Sorensen and Stanton, in press).

This study has also shown that the quality of a team's communications, i.e. their SA transactions, matters. SA transactions support the team in making sense of the situation as it unfolds and enables each team member to perform their task and therefore contribute to overall team success. Transactional SA is also the means by which Distributed SA can emerge within the teams and it is clear from the analysis that the Distributed SA which had emerged in the twelve teams differed.

7.5 Conclusion

Using a systems approach to team analysis, this chapter set out to explore the interactions which take place within teams which have performed more effectively and contrasted these with those of teams that have performed less effectively. In so doing this chapter sought to build on the findings of Chapter 6 which showed that there is a relationship between performance and Distributed SA. The study presented here explored the nature of the SA transactions evident in the team communications, to shed light on the role these play in the coordination of team performance and to explore what encourages teams to function optimally. The analysis showed that the more effective teams were characterised by, not only a high volume of communications and transactions, but by three different types of transactions which were evident in different volumes throughout team performance.

The findings presented in this chapter were exploratory in nature, as such, it is not possible to draw firm conclusions regarding whether the different types of transaction and the utilisation of these have any causal bearing on the task performance. These findings, however, raise interesting further questions with regards to the way in which Distributed SA manifests itself and develops in a team. For instance, one reason why the less effective teams performed worse than the more effective teams may be a lack of compatible SA, i.e. team members were not able to make use of the transactions which did take place in their interactions. Stanton et al. (2009c; 2009d) explained that when the SA of individuals becomes compatible during task performance, that transactions of SA can occur. It stands to reason that if there were no, or few, such overlaps then fewer transactions may result. Transactions which do occur may not be used by team members it was intended for, or the team has an insufficiently developed transactional memory to enable access to the right information. Clearly, this issue deserves further investigation. Chapter 8 will therefore explore the nature of compatible and incompatible SA transactions in teams.

8 Exploring Compatible and Incompatible Transactions in Teams – Implications for Distributed SA

8.1 Introduction

The Distributed SA approach views team SA as an entity that is separate from team members (Salmon et al., 2008). In this perspective SA is a characteristic of the system itself (Artman and Garbis, 1998; Salmon et al., 2008). Stanton et al. (2009c; 2009d) argued that where there is no compatibility of individual SA there cannot be adequate opportunity for transactions of SA to be passed around the system. This reduction in SA transaction opportunities may contribute to breakdowns in SA.

As highlighted in the previous chapter, SA transactions are a critical commodity in the development of Distributed SA in teams. As yet, little is known of the nature of compatible and incompatible transactions and the role these may play in Distributed SA. Transactions which take place in a team may not be used by team members in the manner it was intended and, therefore, could play a role in SA breakdown. This requires further exploration. In order to understand the occurrence of SA breakdowns or 'lapses' in SA, understanding all aspects of the phenomenon is necessary (Simmons, 2003; Bundy, 1994). This necessitates that the role of the component of SA which has yet to be explored in this thesis, namely compatible SA, is explored. This chapter therefore seeks to shed light on the manner in which compatibility and incompatibility of SA transactions manifests itself in teams. Given the lack of prior research in this area it was decided that an exploratory analysis would be best placed to reveal the manner in which compatible and incompatible SA transactions contribute to the regulation of teams' behaviour and contribute to the development of Distributed SA.

In Chapter 2 Salmon et al. (2008) were cited as explaining that:

> "Distributed SA approaches assume that collaborative systems possess cognitive properties (such as SA) that are not part of individual cognition" (p.312).

Similarly, Artman and Garbis (1998) suggested that team performance in complex systems requires a focus on the team as a whole system. SA is not only distributed across the agents who make up the team but also in the artefacts that they utilise

(Artman and Garbis, 1998). The measurement of Distributed SA therefore depicts the system SA as information networks, which shows:

> "where what an agent 'needs to know' in order to achieve success during task performance" (Salmon et al., 2008, p. 313).

Chapter 7 showed that access to information is dependent on knowing who knows what, or transactional memory. Salmon et al. (2008) further stated that:

> "The ownership, usage and sharing of knowledge is dynamic and dependent on the task and its associated goals. Agents therefore have different SA for the same situation, but their SA can be overlapping, compatible and complementary and deficiencies in one agent's SA can be compensated by another agent" (p. 313).

Patrick et al. (2006) argued that comparisons between teams are important as such comparisons will provide insights into the phenomenon of SA. In order to enable a comparison of teams based on their SA a full understanding of the nature of Distributed SA is needed. As described in Chapter 2, Stanton et al. (2006) outlined the Distributed SA theory as consisting of four concepts. Three of these are considered in this chapter; Schema Theory, genotype and phenotype schema and the Perceptual Cycle Model of cognition.

8.1.1 Schema theory

Schema theory, based on the work of Bartlett (1932), explains the production of behaviour as an organisation of experience which are drawn when dealing with a current situation (Stanton et al., 2009d). Stanton et al. (2009d) explained that the schemata held by a person combines with the goals they hold, tools they use and the situations they find themselves in to generate, or blend, new behaviour. Individuals gain different experience and as a result may hold different schemata.

Grasser and Nakamura (1982) argued that schemata are generic knowledge structures which serve to guide interpretation of external information. Marshall (1995)Marshall (1995)Marshall (1995) explained that these knowledge structures can be represented as a network of associations. Schemata have been described as:

> "hierarchically organised sets of units describing generalised knowledge about an event or scene sequence" (Mandler, 1984, p.14).

Actions are specified only at the highest, abstract, level and activation of a higher-order schema leads to the activation of lower level schemata to complete a sequence of behaviour (Norman, 1981). Norman and Shallice (1986) defined the higher order schemata 'source schema' and lower-level schema 'component schema'. Component schema, when activated through the source schema, become source schema in their own right as a person runs through the sequence of actions required for performing some task. As an example, "making a stew" may be a source schema which triggers a number of component schemata such as "preparing beef" which in turn become a source schema for "cutting meat", and so on. Schemata are therefore structured in a hierarchical manner (Plant and Stanton, 2012).

Graesser and Nakamura (1982) differentiate between mental models and schemata by the example "restaurant eating schema". They state that this schema is generic for any restaurant a person might visit, whilst a mental model would have to be related to individual restaurants and the specific time at which the restaurant is visited (Plant and Stanton, in press). An individual's schemata will be combined with the goals they possess and the situation they find themselves in to develop new types of behaviour (Stanton et al., 2009d). In the following this idea is considered in more detail.

8.1.2 Genotype and phenotype schema and their role in SA

The notion of schemata is closely linked with ideas of memory and knowledge. Neisser (1976) argued that schema aid the organising of knowledge about the world. Smith and Hancock (1995), similarly, argued that SA can be considered:

> "a generative process of knowledge creation" (p.142),

Neisser (1976) suggested that schemata exist as both genotype and phenotype schemata. The genotype influences the development of the cognitive and behavioural makeup of an individual (Stanton et al., 2009d). Phenotype schemata become the expression of the potential latent in the genotype that is manifested in behaviour (Stanton et al., 2009d). Individuals possess genotype schemata, i.e. the sum of all experience, that are triggered by a task, phenotype schemata are then utilised in task performance and can be examined in, for example, performance data (Stanton et al., 2009d) or in communications.

Walker et al. (in press) stated that they:

> "refer to SA as 'constructive'…the… [human] is part of the situation they find themselves in and can influence its dynamic" (p.3).

This idea draws on Neisser's (1976) Perceptual Cycle Model. Smith and Hancock (1995) also draw on Neisser's model when explaining how SA functions. They stated that the environment informs the individual and alters their knowledge, whilst knowledge (e.g. schemata) directs the individual's actions (Smith and Hancock, 1995). The actions in turn may change the environment which impacts on the knowledge of the individual, beginning the cycle again. Neisser's model explains the cyclical process of interaction between individuals and their environment.

Schemata therefore support the person in dealing proficiently with situations in that they assist the production of appropriate responses (Stanton et al., 2009d). However, this is contingent on the appropriate schema being activated. Norman and Shallice (1986) attempted to explain the triggering of inappropriate schemata as contention scheduling, a phenomenon which is described in detail below.

8.1.3 Contention scheduling

Norman and Shallice (1986) proposed a theoretical framework for human attention to action:

> "structured around the notion of a set of active schemata, organized according to the particular action sequences of which they are a part, awaiting the appropriate set of conditions so that they can become selected to control action" (p.1).

Their analyses focused on external actions and distinguished between automatic and conscious actions (Norman and Shallice, 1896). They go on to explain that:

> "when numerous schemata are activated at the same time, some means must be provided for selection of a particular schema when it is required. At times, however, there will be conflicts among potentially relevant schemata and so some sort of conflict resolution procedure must be provided" (p.4).

In many areas of teamwork one course of action must be chosen and agreement within the team must be established if a common goal is to be met in a timely manner. This poses the question of how teams resolve a conflict between opposing ideas or views on what the right course of action may be. Chapter 7 proposed that a high number of 'situation reports' informed other team members of what one agent knows. These forms of transactions, interspersed by 'requests' and 'orders' also spreads ideas about what the team should be doing, in terms of a strategic overall game plan as well as immediate courses of action. Building on the work presented in Chapter 7 this chapter considers the information passed around in the team. In particular, the information is explored to reveal whether the information triggers a number of alternative courses of action from which one must be chosen, explained as contention scheduling (Norman and Shallice, 1986). Norman and Shallice (1986) presented the notion of contention scheduling as a basic mechanism:

> "which acts through activation and inhibition of supporting and conflicting schemata" (p3).

Norman and Schallice (1986) argued that selection of one schema can lead to the triggering of other related source schemata. As a source the schema activates other schemata and can in turn function as source schemata for other related component schemata (Norman and Schallice, 1986). This means that when the schema for "driving" is selected all component schemata related to driving such as acceleration, gear changes and braking may be activated at appropriate times during driving performance (Norman and Shallice, 1986). An activated schema will operate until the task for which it was activated has been completed (Norman and Shallice, 1986) in order:

> "To permit simultaneous action of cooperative acts and prevent simultaneous action of conflicting ones is a difficult job" (Norman and Shallice, 1986, p.5).

Contention scheduling resolves conflict arising from opposing schemata (Norman and Shallice, 1986). A similar process could be expected to be found in teams as they decide between conflicting courses of action.

If novel tasks are to be performed it may be that no prior schema exists so that there are no schemata available to select (Norman and Shallice, 1986). This may be the case in teamwork where adapting to a complex and changing environment, such as those found in military settings, go beyond the bounds of experience of the team members (Walker et al., 2009a). It is therefore likely that in novel situations teams may display more conflicting ideas about what course of action should be taken.

Norman (1981) described situations in which the wrong schemata were selected as a means of describing different types of human error. He suggested that three basic types of schemata account for most errors: activation of the wrong schemata (as described in contention scheduling similar triggering conditions may lead to the wrong schemata being activated), failure to activate appropriate schemata (e.g. lack of attention to the triggering conditions which could have activated the schema) and a wrong triggering of schemata (e.g. triggering of schema at the inappropriate time). Similarly, Rafferty et al. (2012) reported a study in which a team committed an act of fratricide. They describe how 'confirmation bias' lead to a fixation upon one course of action, or one schema (Rafferty et al., 2012; in press). In so doing all extraneous information was dismissed and an act of fratricide resulted. Similar findings were reported by Plant and Stanton (2012) who explored the Kegworth Disaster (1989, UK), using the Perceptual Cycle Model. They described the accident where a Boeing 737-400 crashed after the pilots shut down the wrong engine leading to the aircraft crashing with a significant loss of life. Plant and Stanton (2012) present a schematic explanation of the errors which led to the accident and argued that Schema Theory offered insight into the causal explanations of the errors observed. Fundamentally, they identified that the pilots:

> “shut down the wrong engine due to inappropriate diagnosis of smoke origin” (p.306)

The pilots had the wrong schemata for the situation triggered as a result of prior experience (Plant and Stanton, 2012). They explained this phenomenon as schema-induced error (Plant and Stanton, 2012).

The study reported here aimed to consider whether any of these schema related error conditions are related to instances of incompatibility in teams. In order to do so the role and nature of compatible SA in teams must be considered.

8.1.4 The role of compatible SA

Salmon et al. (2008) explained that each agent may hold different SA for the same situation. The individual is governed by their specific team role, tasks and goals in the manner in which they perceive the situation as it evolves (Stanton et al., 2009d; Salmon et al., 2008). This is closely linked with Schema Theory, as described above, which argues that each individual holds different schemata (as the sum of their experiences) and that no schema will be identical between two individuals (Stanton et al., 2009c; Stanton et al., 2009d). This is also closely linked to the idea that it is not necessary for the whole team to know everything (Salmon et al., 2008; Hutchins, 1995a). This was argued in Chapter 7 where transactional memory and SA transactions were shown to be linked. Successful team performance depends on knowing who knows what to access information, not knowing everything. Given the difference between individual team member's schemata and interdependent tasks awareness is not shared (Salmon et al., 2008). One team member’s SA could therefore be different but remain compatible as their SA will be required to ensure that the team can perform successfully (Salmon et al., 2008). This was argued by Stanton et al. (2006) who asserted that team members have unique but compatible portions of awareness. In other words, that the team requires separate awareness but also compatible awareness whilst working towards a goal (Salmon et al., 2008). It has been argued that it is compatible SA which holds distributed systems together (Stanton et al., 2006a; Stanton et al., 2009c; Stanton et al., 2009d; Salmon et al., 2009a; Salmon et al., 2010). Indeed, Salmon et al. (2008) pointed out that Distributed SA:

> "refers to the systems overall awareness comprising each of its component agent's compatible SA" (p. 381).

Stanton et al. (2006a) described how each agent within the team plays an important role in the development and maintenance of other agents' SA. When teams are performing well it could be assumed that the team has a large degree of compatible SA, whereas the opposite may be true when incompatibility is found.

The above discussions of compatible SA points to the fact that whilst it is not necessary for everyone to know everything, all team members need to have some idea of what they are supposed to be doing. In military literature this is called "command intent" (see Shattuck and Woods, 2000; Connor, 2000). Conveying the command intent (or game goals in the experimental design) is done by SA transactions, as explained in Chapter 7. In this way connections between different parts of a system, or team, are maintained where necessary.

The diverse but related literature described here point to a number of pertinent questions which may shed light on the role of schemata and compatible SA in the team's development of Distributed SA. As such, this chapter aims to explore the presence of schemata and the compatible and incompatible transactions associated with these, as observed in the communication data. This is done in order to further develop an understanding of Distributed SA in teams, whilst applying the notions of schemata as regulators of behaviour to the workings of a team. The exploratory research presented here was therefore guided by the following research questions:

1. Do teams exhibit the use of source schemata and component schemata (Norman and Shallice, 1986; Grasser and Nakamura, 1982; Plant and Stanton)?
2. Are conflicts of schemata, such as that described as contention scheduling, observed in team communications (Norman and Shallice, 1986)?
3. Do the team members exhibit transactions of information which are either compatible or incompatible and associated with a component schema (Stanton et al., 2006a; Stanton et al., 2009c; Stanton et al., 2009d; Salmon et al., 2008)?

8.2 Method

8.2.1 Research design

A qualitative approach was chosen to explore the data and shed light on the three research questions detailed above. The research utilised two qualitative approaches; a top-down approach in which the game rules were used as a guide to identify schemata and a bottom-up process where content analysis was utilised to explore compatible and incompatible transactions observed in communications.

As described in Chapter 6, MSN was used as the medium through which the teams could communicate. The use of MSN ensured true interdependency of team performance (e.g. in that all team members were required to complete the task). The communication data from the four teams were extracted and explored to identify schemata and the compatible and incompatible transactions associated with these.

8.2.2 Experimental tasks

All teams performed the eight experimental tasks of the strategy game detailed in Chapter 6 (see section 6.2.3). The team collaborated to achieve the aim of the game which was to take as many red players as possible whilst at the same time avoiding taking yellow, green or blue (e.g. other team members) players. Collaboration in the teams was ensured through communication. The rules of the game were the same as those given in Chapter 5 (see section 5.2.3).

8.2.3 Data reduction and analysis

Communications were explored using content analysis to identify compatible and transactional information elements, using a similar approach to that applied by Stanton et al. (2009c; 2009d) among others (Salmon et al., 2008; 2009a). In the following the data analysis of command intent, schemata and contention scheduling and compatible SA are described.

Schemata and contention scheduling

Using Norman's (1981) and Norman and Shallice's (1986) description of source and component schemata the most prevalent source schemata were identified. Norman and Shallice (1986) defined source schema as a "highest-order control" mechanism which organises a set of learned action sequences.

> "The term 'source' is chosen to indicate that component schemata can be activated through the source" (Norman and Shallice, 1986, p.6).

They go on to explain that when a source schema for an activity has been selected, such as for driving a car, all component schemata are activated for acts such as steering, accelerating, turning and so on. A component schema can therefore be seen as a lower-order schema which achieves some part of the actions which the higher-order, or source, schema initiates.

The source schema expected for all experiment games was "win game" from which component schemata such as "take" originate and in turn become a source schema for a sequence of component schemata. Key game rules are contrasted with expected source and component schemata in Table 8.1 (see section 5.2.3 for the complete list of game rules).

Table 8.1 Key game rules contrasted with expected schemata

	Game Rule	Schemata
1	The aim of the game is to take as many red players as possible	Source schema: Win game Component schema: Take red
2	Each Blue player has one move per turn, however, each player can give their move to another player on a turn-by-turn basis	Component schema: Make moves Component schema: Give away moves
3	Each player can move in any direction but not through another player	
4	Moving through another player constitutes taking	
5	Blue players have to outnumber a red player before they can take it	Component schema: Outnumber red
6	Blue must not take blue, green or yellow players	Component schema: avoid taking non-red

Considering the "take" schema it is clear, based on the game rules, that when this source schema is broken down at least three schemata were available for triggering in the teams:

1. Take only red while avoiding taking yellow
2. Take any player
3. Take red but do not avoid taking yellow, green or blue if they are blocking the access to a red

The communications were therefore explored for source and component schemata and for schemata which were in conflict with each other as described by contention scheduling. The activation of schema is exemplified in Figure 8.1 which shows how the source schema "take" activates the component schema "take red players" (see Figure 8.1 a) whereby "take red players" become a source schema for "avoid taking yellow" (see Figure 8.1 b). The sequence of activation continues until the task the source schema was activated for has been completed. It is also conceivable that a conflicting or opposing schema, such as "take yellow", may be activated leading to the need for contention scheduling to enable a selection of the most appropriate schema.

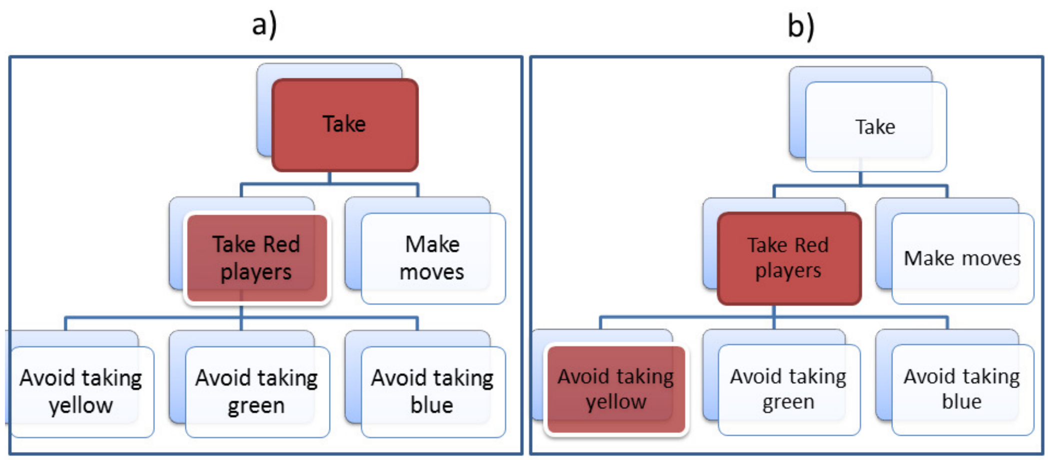


Figure 8.1. Illustration of source and component schemata activation

Compatible and Incompatible SA

A content analysis was performed to code transactions observed in the team's communications. Strauss and Corbin (1998) stated that "*in vivo coding*" is applied to text taken from transcripts of various kinds. This means that the code name applied reflect the words used in the text (Strauss and Corbin, 1998). This is in line with "open coding" which was described by Strauss and Corbin (1998) as:

> "the analytic process through which concepts [e.g. codes] are identified and their properties and dimensions are discovered in data" (p.101).

Such coding anchors the codes in the context in which they are found and as such this manner of content analysis was considered appropriate for discerning between compatible and incompatible transactions in the team communications. The transactions identified were linked to the component schemata they originated from. The transactions observed were then depicted in state-space diagrams, as described below.

State-space diagrams

Sanderson et al. (1989) described the use of state-space diagrams as a means of exploring process control as a dynamic problem solving task. Using state-space diagrams they showed how the operator handled a set of problems and moved from point to point within the state space as they did so. Sanderson et al. (1989) explained that the state space:

> “also serve as a problem space because it is a framework for presenting all goal-relevant states of the system at the chosen grain of analysis. Associated with the each state is an ideal control action, or actions, that will move the system in the desired direction” (p.1353).

The use of state-space diagrams can therefore be used to highlight inaccurate or different knowledge about a system (Sanderson et al., 1989). State-space diagrams were applied in the exploration of the communication transcripts to enable a classification of compatible and incompatible transactions. The state-space diagrams were constructed to show how the understanding of team members changed as new information was provided and how it conflicts with existing assumptions, or schemata. These are described as either assimilation or accommodation, where assimilation reflects instances where the incoming information fits with the schema and where accommodation reflects that new schemata had to be developed (Piaget, 1961). In this way compatible and incompatible transactions are shown. All communicative data was considered to identify the common schemata observed across all teams in task performance, a representative sample of these are explored here.

To enable a further exploration of the data the number of moves made, number of transactions and duration of interaction (i.e. time in seconds) associated with the transactions were noted. The aim being to see whether ‘compatible’ transactions and ‘incompatible’ transactions differed on these measures. In the following section the findings from the exploratory analyses are presented.

8.3 Results

8.3.1 Compatible and incompatible transactions

A common source schema, or a ‘super-source’ schema, observed in all communications was “win the game” from which all other schemata appeared to originate. The component schemata observed from this schema and the manner in which compatible and incompatible transactions between team members developed the schemata are explored here.

Taking red

Figure 8.2 illustrates the manner in which teams’ compatible transactions were passed around the team with regards to taking red.

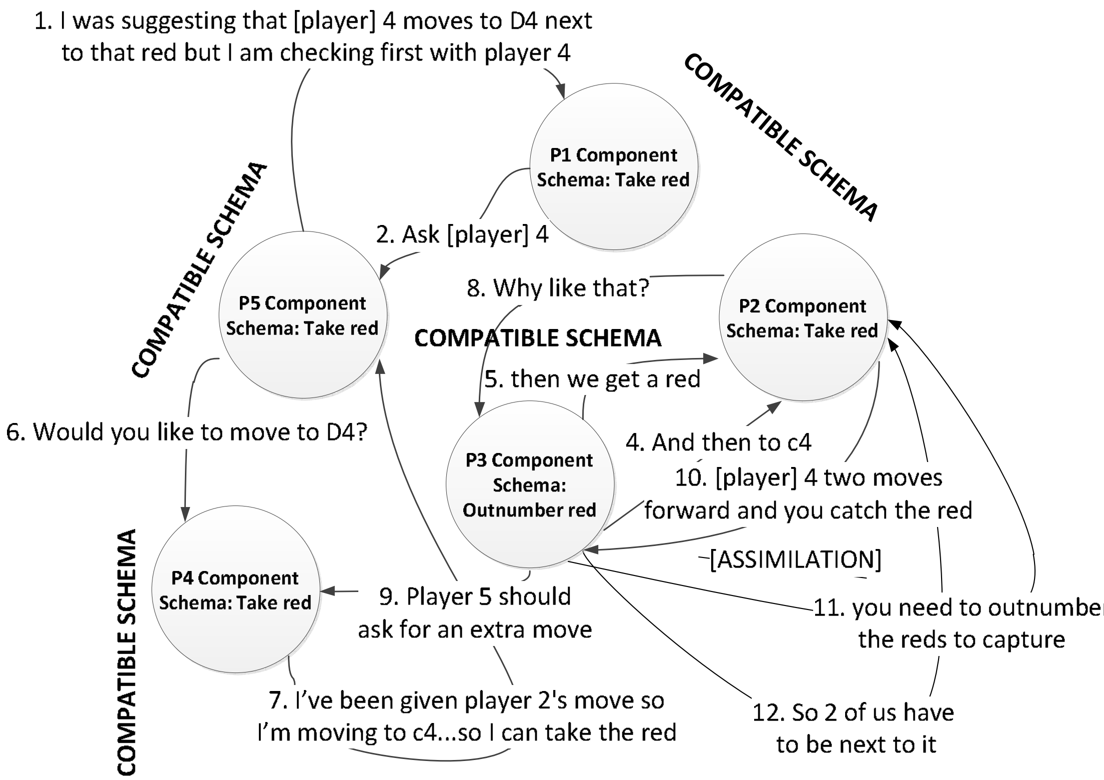


Figure 8.2 State-space diagram showing compatible transactions associated with the schema "take red"

As seen in Figure 8.2, Player 5 suggested to Player 1 that Player 4 moves next to a red player (*"I was suggesting that [player] 4 moves to D4 next to that red"*). Player 3 made a suggestion to Player 2 in terms of another move which would take another player next to red (*"And then to c4"*). This was followed by a statement which asserted that doing so would enable the taking of a red (*"then we get a red"*). This prompted Player 2 to ask why this was necessary (*"why like that?"*). Player 3 appeared to have a component schema for taking red which differed slightly from the other team members, namely that in order to take red the red must be outnumbered first, by there being at least two blue players to every red (e.g. the schema "outnumber red"). This was seen in the transaction from Player 3 to Player 2 where this game rule was explained (*"you need to outnumber the reds to capture" and "so 2 of us have to be next to it"*). Player 3's transaction to Player 2 appeared to have triggered the activation of a further component schema, namely "giving away moves" which Player 3 transacted to Player 4 (*"Player 5 should ask for an extra move"*). Whilst this was a different schema to that held by the other team members this was not incompatible and originated from the source schema "take red".

A total of 11 transactions were made in this cycle, of which the main compatible and incompatible transactions are highlighted in the state-space diagram. The duration of the transactions was 63 seconds with 2 moves being made. Taking red appears to have elicited a number of component schemata such as "making moves" and "giving moves away", these are explored below.

Making moves

The component schema of "moves" was observed in the communications, however, contention was observed between the need to move two or more players in order to be effective. Figure 8.3 shows the state-space diagram developed for the component schema "moves". The schema "moves" has here taken the role of a source schema triggering two different component schema "move two players" and "move three players".

A contention can be seen in the team communications with Player 5 and Player 4 beginning the game with an active schema for "moving 3 players" whilst Player 3, Player 2 and Player 1 have an active schema for "move 2 players". The first transaction, passing between Player 4 and Player 3 (*"Ok, this time, Player 2 and Player 4 and Player 5 straight down to the bottom…"*), appears to arise from Player 4's schema "move 3 players" and was incompatible with Player 3's schema "move 2 players". This resulted in a transaction from Player 3 to Player 4 (*"Suggestion is to just move 2 pieces"*) where Player 3's active schema for moving only two players is conveyed. Through a process of accommodation Player 4 then adapts the original schema for moving three players to two players. Player 5, like Player 4, held a conflicting schema to that of the other team members ("move three players") which is adjusted to "move two players" through the transactions received from Player 4. Player 4 therefore; after having had their schema changed, goes on to initiate accommodation of Player 5's schema. As can be seen in Player 4's transaction to Player 5 where the same message as that Player 4 received from Player 3 was passed on to Player 5 *("Suggestion is to just move 2 pieces")*. Player 5 argued against the proposed strategy initially (*"more flexible if we go with three [players]"*) but relents and, seen in the reply, (*"I do see the merit of his point"*) adjusted his schema to that held by the majority of the team (e.g. "move two player").

A total of 23 transactions were made in this cycle, of which the main compatible and incompatible transactions are highlighted in the state-space diagram. The duration of the transactions was 321 seconds (5 minutes and 30 seconds) with a total of 6 moves made.

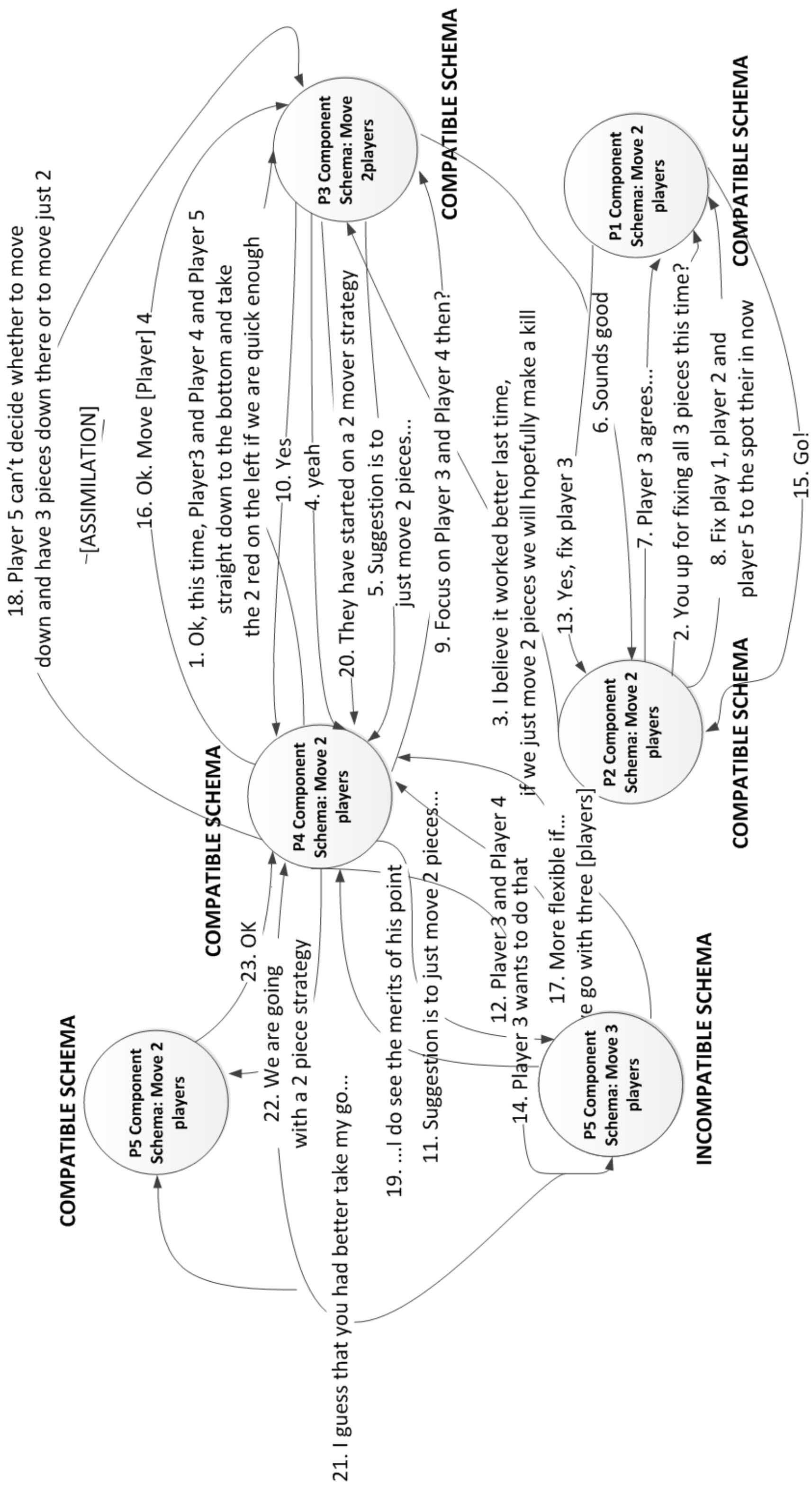


Figure 8.3 State-space diagram showing adjustment of schemata related to moving players

Figure 8.4 shows the compatible transactions being assimilated into the team member's schemata "move towards red". Here, no conflicts are observed and each team member's transactions aligned with the schemata. A total of 9 transactions were made in this cycle, the duration of the transactions was 20 seconds and 2 moves were made during the transactions.

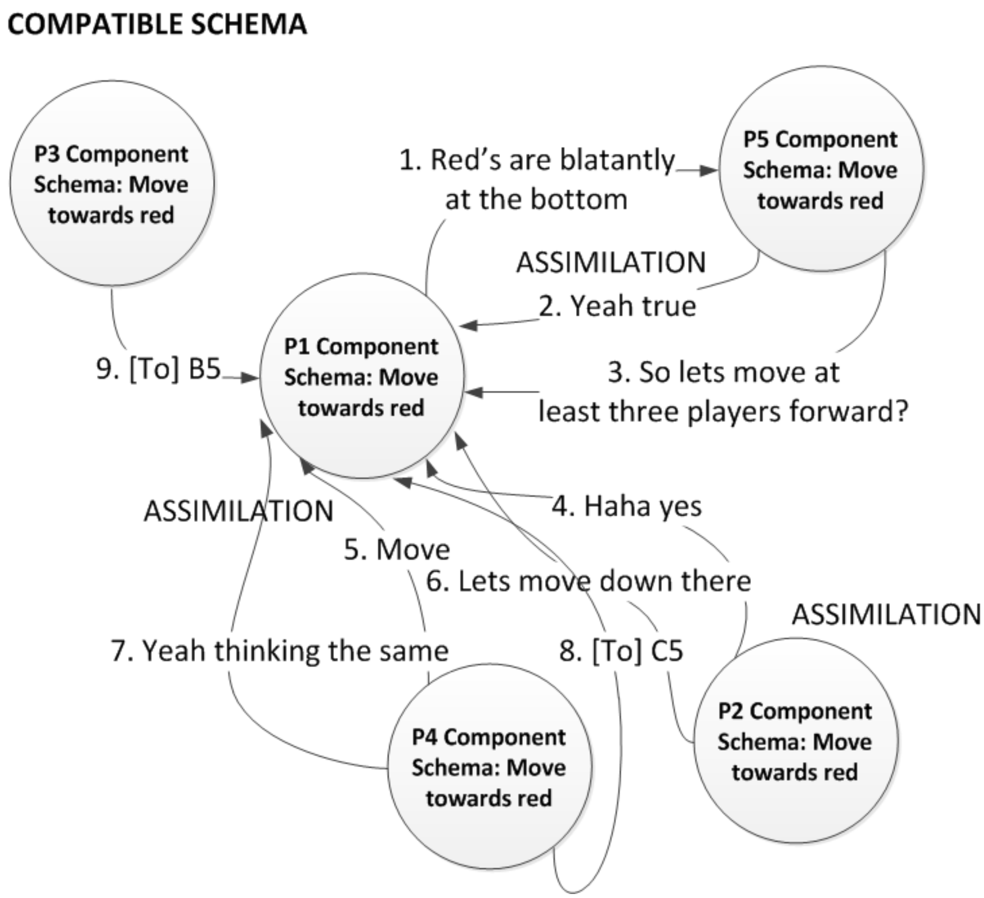


Figure 8.4. State-space diagram showing assimilation of compatible transactions in relation to moving players

Team working

It was evident from the above that in order to make moves the teams had to decide on how to work together. Figure 8.5 explored the compatible and incompatible transactions which arose from two different schemata; "work as a team" and "work independently".

Three schemata can be observed in Figure 8.5, Player 1 held the schema "work as a team" as can be seen in the transactions which originated for Player 1 (*"just spread everyone out"?* and *"it's our turn again"*). Player 3 seemed to have activated a conflicting schema ("Work independently") as expressed by the incompatible transaction to Player 1 (*"I think we should do this pretty much independently"*). Player 1's transaction; however, led to an accommodation of this information which altered Player 3's schema to "work as a team". Player 3 then offered their move to Player 2 (*"Take my moves, I get stuck behind other players"*) which seemed to trigger the component schema "give away moves" for Player 2. Player 1 suggested to Player 2 that they should share moves (*"we probably should just go straight down the board with two using other's moves?"*) leading to assimilation of the compatible transaction in Player 2's schema. Player 5 appeared to have activated the same schema (e.g. "give away moves") as seen in the transaction between Player 5 and Player 2 (*"If we share our moves, we will be able to take at least one red"*). For Player 5 and Player 2, therefore, it would seem that working as a team involves giving away own moves to other team members who might need them.

A total of 11 transactions were made in this cycle, of which the main compatible and incompatible transactions are highlighted in the state-space diagram. The duration of the transactions was 190 seconds with 5 moves being made.

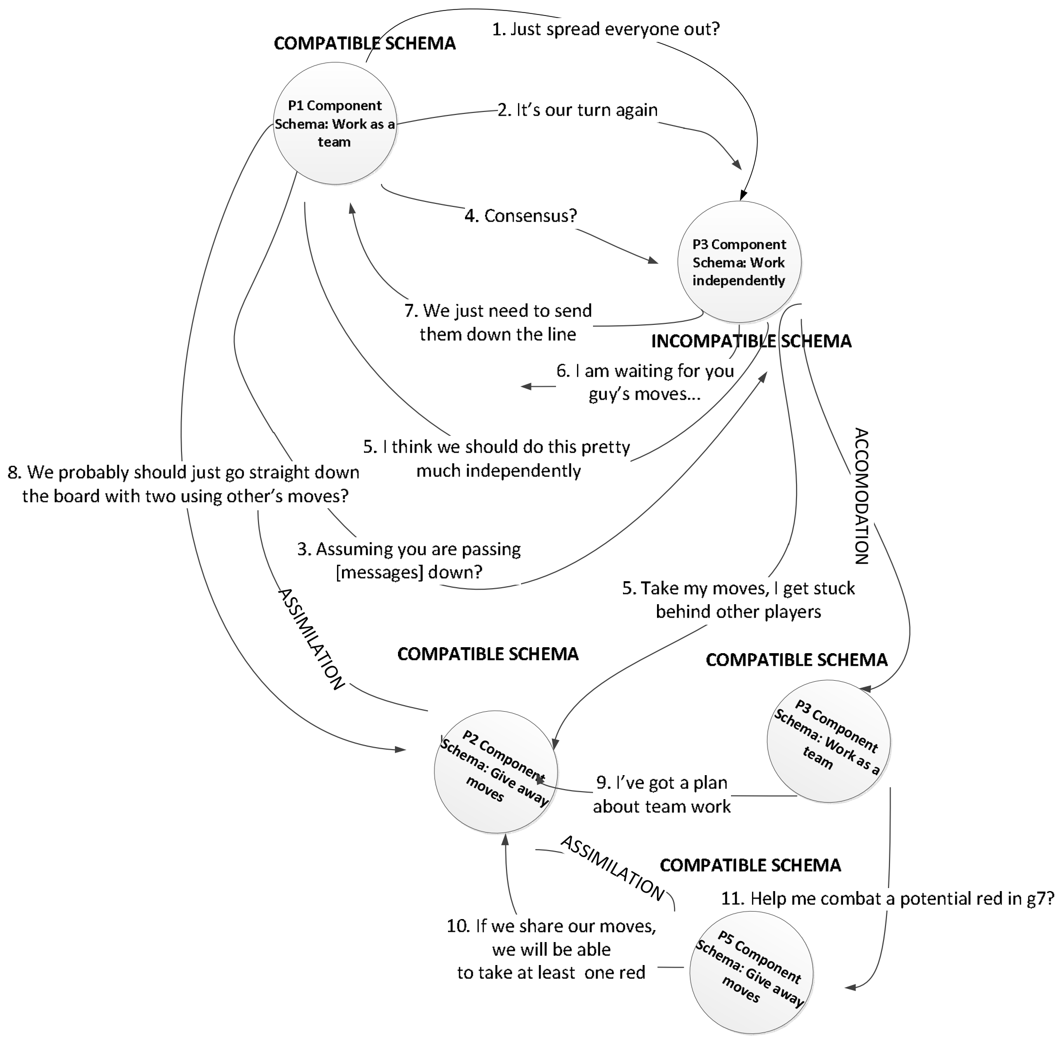


Figure 8.5. State-space diagram showing compatible and incompatible transactions relating to team work

Further exploration of the communication transcripts revealed the same schema "work as a team" existing also with no incompatible transactions in a different team, as seen in the state-space diagram in Figure 8.6 .

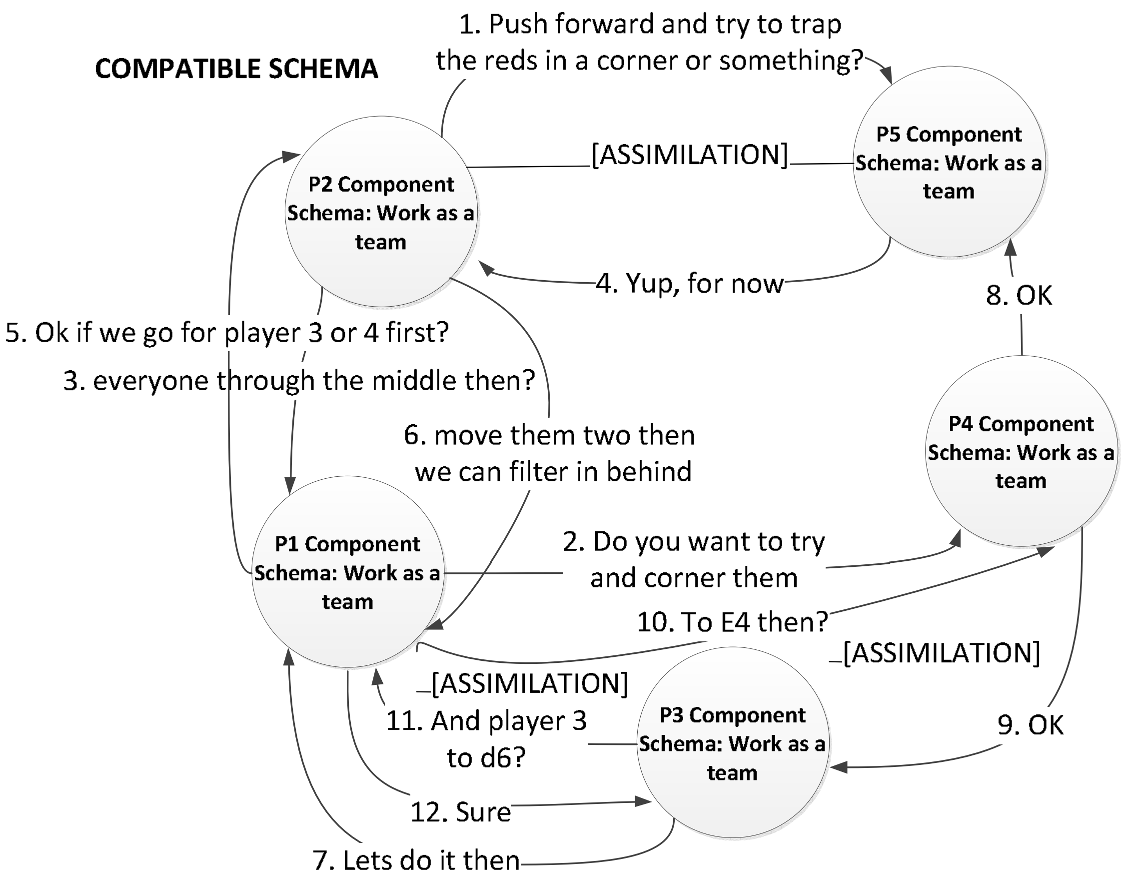


Figure 8.6. State-space diagram showing compatible transactions concerning the manner in which a team should work

Player 2 revealed a schema for working together as a team in the transaction made to Player 5 (*"push forward and try to trap the reds in a corner or something?"*) and in the transaction to Player 1 (*"everyone down the middle then"*). Player 5 held a similar schema as revealed in the reply to Player 2 (*"yup, for now"*). General agreement can be seen in the compatible transactions passing between the different team members, leading to assimilation of these transactions with the existing schemata's each team member held.

A total of 9 transactions were made in this cycle, of which the main compatible and incompatible transactions are highlighted in the state-space diagram. The duration of the transactions was 221 seconds (4 minutes and 8 seconds) with 2 moves made.

The main purpose of the strategies the team's established for their manner of working was to take as many red as possible. No conflicting schemata were observed in the communications between team members indicating that the "take red" schema was an important source schema from which other schemata were triggered, as explored below.

Taking yellow

The schema "take red" appeared to have elicited component schemas for the game rule that stipulated that yellow players should not be taken. This schema, however, also triggered competing schemata in teams which appeared to encourage the taking of yellow players in order to take more red players, see Figure 8.7 below.

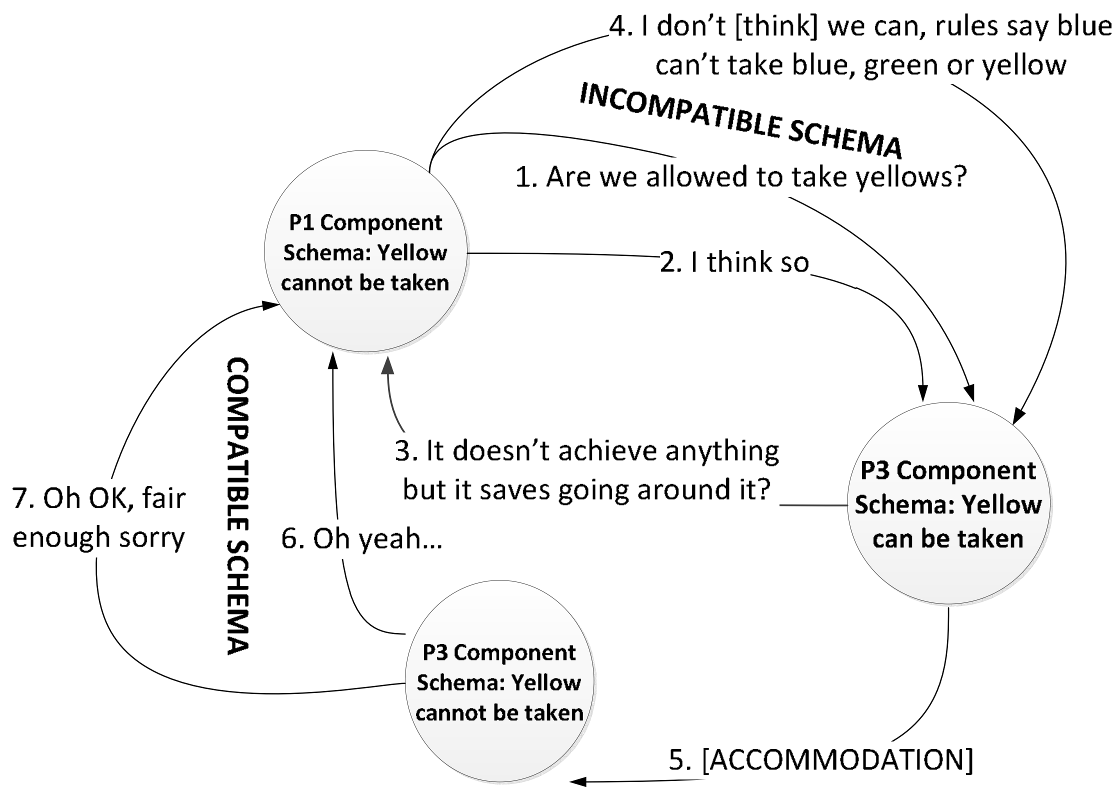


Figure 8.7. State-space diagram showing compatible and incompatible transactions concerning the taking of yellow players

Player 1 appeared to have activated the component schema "yellow cannot be taken" but tests the soundness of this schema by asking Player 3 whether they are allowed to take yellow players in the game (*"Are we allowed to take yellows?"*). Player 1 follows this question up and answers independently (*"I think so"*). This appeared to trigger the component schema "yellow can be taken" for Player 3 (*"it doesn't achieve anything but it saves going around it?"*). Player 1 then replied with a confirmation that the game rules did not allow the taking of yellow (*"I don't [think] we can, rules say blue can't take blue, green or yellow"*). This incompatible transaction which presented Player 3 with information in opposition to their active schema led to the triggering of the schema "yellow cannot be taken" through a process of accommodation as seen in the transactions made by Player 3 that are compatible with the schema (e.g. *"Oh yeah…"* and *"Oh OK, fair enough sorry"*).

A total of 7 transactions were made in this cycle, of which the main compatible and incompatible transactions are highlighted in the state-space diagram. The duration of the transactions was 68 seconds (1 minutes and 8 seconds) with 2 moves made. Communications revealed another schema active in the teams, "revealing yellow", as explored in Figure 8.8 below.

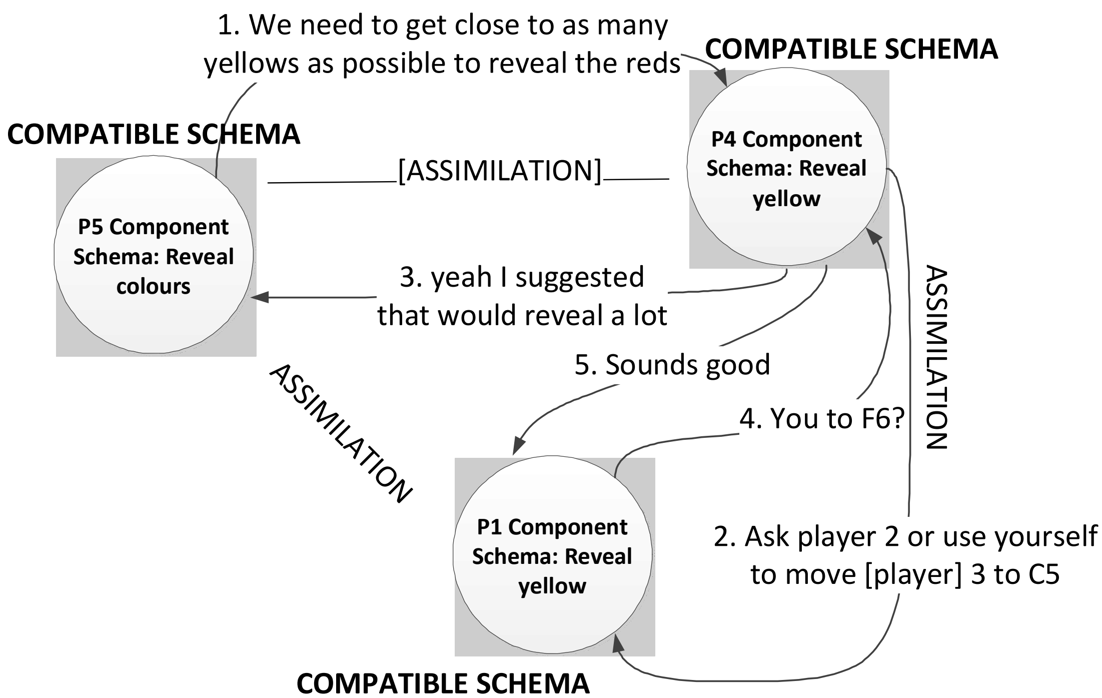


Figure 8.8. State-space diagram showing compatible and incompatible transactions concerning revealing of yellow players

Player 5 appeared to hold a schema for "reveal colours" as seen in the transaction made to Player 4 (*"We need to get close to as many yellows as possible to reveal the reds"*). This transaction was assimilated into Player 4's compatible schema who counters that suggestions made by Player 4 that this would reveal a lot of yellow players (*"yeah I suggested that would reveal a lot"*). Player 1, similarly, holds a compatible schema to Player 4 as seen in the agreement and suggestions in terms of placement of respective players close to where the yellow players were in the game board configuration.

A total of 5 transactions were made in this cycle, of which the main compatible and incompatible transactions are highlighted in the state-space diagram. The duration of the transactions was 49 seconds and a total of 6 moves were made. A summary of the results are given below.

8.3.2 Summary of results

When contrasting the state-space diagrams and the compatible and incompatible transactions explored in these, it appears that the compatible transactions are associated with making more moves with a lower number of transactions.

The transactions explored were associated with a range of schemata, where two were in direct contention with other component schemata, as illustrated in Figure 8.9 below. In the following section these exploratory findings are discussed.

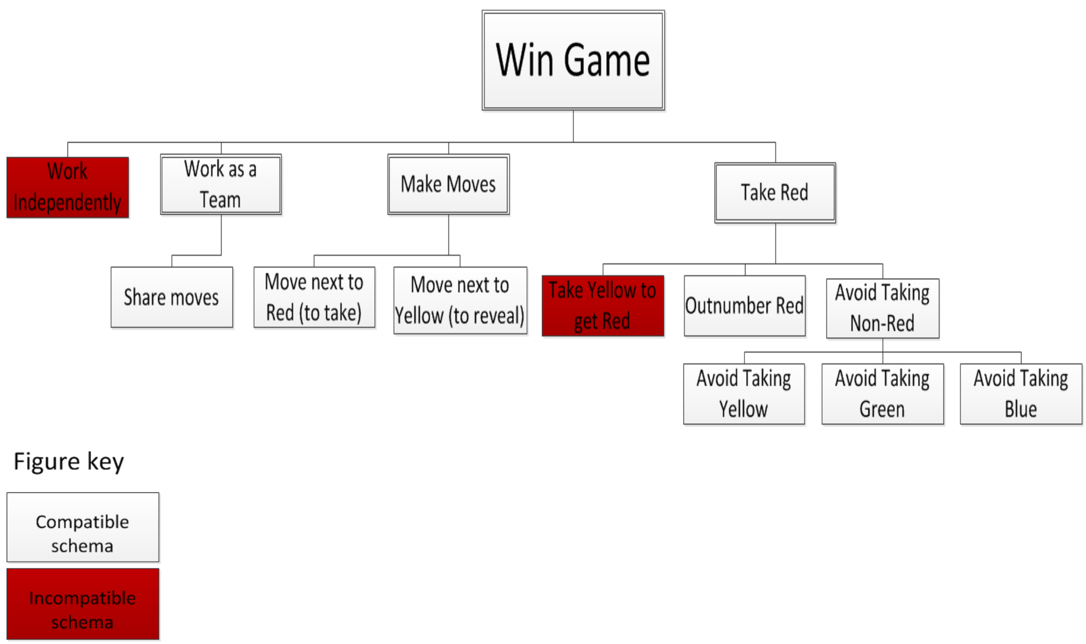


Figure 8.9. Summary of compatible and incompatible schemata activated from the source schema "win game"

8.4 Discussion

Teams are interdependent entities from which Distributed SA emerges through interactions between team members (Stanton et al., 2009c; Stanton et al., 2009d; Salmon et al., 2008). The team's interdependence means that each team member performs separate but related tasks to enable the team to achieve an overall goal. Understanding the role of transactional and compatible SA in holding different parts of a system, or team, together is important to further the theory of Distributed SA. This exploratory research sought to shed light on the manner in which compatible and incompatible transactions support the regulation of team behaviour and the development of Distributed SA.

Three research questions guided the exploratory analyses conducted for this chapter. The first asked whether the teams exhibited use of source and component schema. The findings presented here showed that all teams exhibited the activation of source schemata which in turn triggered the activation of component schemata, as described in the literature (e.g. Norman, 1981; Norman and Shallice, 1986).

The second research question asked whether the teams exhibited contention between schemata, as described by Norman (1981). The findings revealed that whilst the triggering of component schemata was mostly appropriate for the context of the game variant played, the triggering of subsequent schemata clearly made the team members vulnerable to activation of inappropriate schemata. The findings highlighted one example of "wrong triggering of schemata" (Normal, 1981) where the team activated a schema which was inappropriate at that time but which could potentially have been appropriate at another time (e.g. in a different type of game). As was seen in the team which held conflicting schemata concerning team working strategies (e.g. work as a team or work independently). Salmon et al. (2008; 2009a) argued that deficiencies in one agent's SA can be compensated by another. This was exemplified when a team member who displayed the wrong schema adjusted it via accommodation whereby information that conflicted with the original schema was used to develop a new schema (as seen in Figure 8.6). Similarly, in discussing taking a red player the team members supplemented each other's understanding of the manner in which red was to be taken (for instance, by being outnumbered).

Norman and Shallice (1986) explained that individuals may not possess schemata for novel tasks. In such instances no schema will be available for selection and a new schema must be developed. Neisser (1976) described that a person's schema combine with the goals they hold and the situation they find themselves in to generate new behaviour. An agent therefore draws on existing experience and knowledge whilst interacting with the world to form a new schema appropriate for the novel task. This may in turn lead to wrong schemata being developed as the interpretation of the new task may not be entirely fitting. This was exemplified in the team communications where a team member had developed a schema for taking yellow as a means by which red players could be got to. The application of previous experience and schemata, which may not be appropriate, may be a rational means by which the teams instigate behaviours. Whilst the schema may be incorrect for a particular game variant expressing it means it becomes possible for the team to adapt it in light of conflicting transactions made by other team members. This is in line with the explanation offered by Bartlett (1936), and early Schema Theory, that the production of behaviour arises from an organisation of experience which are being drawn on in dealing with a situation (Stanton and Stammers, 2008; Plant and Stanton, 2012; Plant and Stanton, in press).

The sequence of activation of a source schema and associated component schemata that were evident in the team's transactions also showed that the team quickly adapted their behaviour to the context, once it was understood, and this led to a triggering of further schemata and acts relating to those. Stanton et al. (2009d) argued that schemata support individuals to proficiently deal with situations in the production of appropriate responses. Such adaptive behaviour is described by Niesser (1976) in the Perceptual Cycle Model. This was exemplified in the extract of communications where taking a yellow was discussed. Player 1 had an active schema for taking a yellow and expressed this to Player 3. Player 1's schema was therefore transacted to Player 3 who had the same schema triggered. Player 1 then appeared to have checked the game rules whilst Player 3 checked the board and found neither that taking a yellow was allowed by the game rules nor gave any advantage in terms of movement on the board. The "taking of a yellow" schema was then dismissed and a new schema activated. The players went on to discuss making moves around the yellow. Applying the Perceptual Cycle Model (Neisser, 1976) to the example above it is clear that the players had a:

> "cognitive map of the world and its possibilities" (Neisser, 1976 cited in Stanton et al., 2009d, p. 482).

This cognitive map directed their perceptual exploration, as seen in their brief discussion with each other as to whether taking a yellow might be acceptable. Player 1 was then prompted to check the game rules and Player 3 to consider the status of the game board, which is akin to extracting environmental information. The Perceptual Cycle Model therefore appears to describe the dynamic interaction the players engaged in, as argued elsewhere (e.g. Plant and Stanton, 2012; Plant and Stanton, in press; Rafferty et al., 2012; Stanton et al., 2009c; Stanton et al., 2009d).

The third research question asked whether contention scheduling was observed in the team communications. The communication extracts presented here did show a degree of conflict between different team members' opposing schemata. Norman and Shallice (1986) explained that when several schemata are activated at the same time selection between these is required. A conflict resolution procedure must then be provided and it would appear that transactions, in conveying what an agent knows, has a 'conflict scheduling' (Norman and Shallice, 1986) function in the teams. Compatible and incompatible transactions, through a process of assimilation and accommodation (Piaget, 1961), appeared to enhance and develop the schemata of other team members, thereby resolving the contention. Given the exploratory nature of this research limited conclusions can be drawn from this study with respect to contention scheduling in teams. It appears that when a conflict existed between team members (as where a yellow player was considered taken and a team member insisted that taking this course of action would be wrong) a resolution was found. It may be that in teams, like the ones studied here, conflict resolution occurs through the schema of a team member with high status being given higher 'activation threshold' in the team, resulting in this schema being triggered when in conflict with a "lesser" team members' conflicting schema. Such scenarios are commonly found in military C2 and in hierarchical teams where one leader is in charge. The activation threshold value given to team members schemata could, perhaps, be reduced or increased by aspects such as whether their schemata have been appropriate for other situations before (i.e. dependent on team members experience) and therefore build on trust and cohesion. It is also possible that where a more democratic team structure exists, the schema which is held by most team members will be given the highest activation value and thus is selected for team behaviour. This is supported by the finding that compatible transactions were associated with a lower number of transactions concurrent with a higher number of moves when contrasted to incompatible transactions. As such, more moves were made with fewer transactions than for the incompatible transactions. The absence of contention scheduling between component schemata held by different team members may explain why fewer transactions were required. In these instances the teams' attention was focused on making the moves rather than establishing the appropriate schema.

Compatible SA, to a larger or lesser degree, is a prerequisite for allowing transactional SA to pass around a team. Transactional SA may be instrumental in ensuring that all team members are aware of the purpose of the game, in that all team members are provided with a description of how other team members understand the situation (such as in 'situation reports' described in Chapter 7). In combination therefore, transactional and compatible SA, ensure that the team is held together in attempting to solve the tasks which follow from the teams understanding, or schemata, of the games' intent. The resulting Distributed SA becomes overarching awareness which allows the team to work together towards this common goal, whilst incorporating the individual team members compatible SA (Salmon et al., 2008). Distributed SA focuses on the system or team as a whole (Artman and Garbis, 1998), Stanton et al. (2006a) showed that the application of Schema Theory, in applying the notions of genotype and phenotype schemata, enabled a consideration of the individual agent's contribution to the overall system SA (Stanton et al, 2009d; Stanton et al., 2009c; Salmon et al., 2008; Salmon et al., 2009a). This was achieved by considering the expression of genotype, or source schemata. The process of contention scheduling in aiding the selection of competing schemata support the expression of phenotype schema seen in local behaviour.

The literature discussed in Chapter 6 highlighted the pitfalls of SA breakdown; potentially leading to human error and in some instances fratricide (Simmons, 2003; Bundy, 1994) and Chapter 7 illustrated the role of SA transactions in enabling Distributed SA to emerge. Compatible SA, in enabling SA transactions to take place, is therefore vital to the development and maintenance of the teams' Distributed SA. The findings presented in this chapter highlighted that the schemata of individual team members must also be taken into account when attempting to understand SA both in terms of breakdowns and efficiently developed SA.

This study set out to explore the role of compatible and incompatible transactions in teams whilst applying ideas from Schema Theory to the workings of a team. The exploratory nature of this research has shed some light on the role of compatible and incompatible transactions in teams. A complete understanding of all aspects of Distributed SA is necessary if potential use of the phenomenon is to be fully exploited in the organisation of teams, distribution of information and design of systems (Salmon et al., 2009a). Schemata and in particular the notions of contention scheduling, schema-driven errors and the Perceptual Cycle Model, supports the ideas presented in the Distributed SA approach by explaining the way in which previous experience and knowledge amassed by each team member may shape their interactions with the world.

These findings also indicate that the Perceptual Cycle Model can be scaled up to explain team's dynamic exploration of, interaction with and adaptation to their environment. Schemata, then, are generic knowledge structures which serve to guide interpretation of information (Graesser and Nakamura, 1982) and should be explored along with the transactional SA and compatible SA in explaining the emergence of Distributed SA in teams. These findings are interesting and shed light on the manner in which teams may trigger each other's schemata and adapt to the environment in a more effective manner. As such, these findings support those presented in Chapter 7.

8.5 Conclusion

The literature described here points to a number of pertinent questions which may shed light on the role of schemata and compatible SA transactions in the team's development of Distributed SA. This study aimed to develop the understanding of

Distributed SA in teams further whilst applying the notions of schemata as regulators of behaviour to the workings of a team. Compatible and incompatible SA transactions appear to be fundamental in the development and activation of schema.

As can be expected from exploratory research more questions are raised than answered. The work presented in this chapter has resulted in a number of research questions which could be taken forward into future work. The role of schemata in Distributed SA, in particular, its role in mitigating between transactional SA and compatible SA should be explored further. Further exploration should seek to gain a fuller understanding of how schemata and the compatible but related aspects of individual team member's awareness impact on the team's adaptation to their environment. Research utilising the notions of schema and the Perceptual Cycle Model seem a worthwhile undertaking.

This chapter concludes the empirical part of this thesis. In the next chapter the main contributions to the literature offered by this body of research will be discussed in light of the empirical and analytical advances to the theory of Distributed SA specifically and the field of SA and team SA more broadly.

9 Key Contributions and Future Research

9.1 Introduction

The overall aim of this research was to validate and advance the theory of Distributed SA as originated by Stanton et al. (2006a) and further developed by Salmon et al. (2009b). This has been done by exploring the concept of SA in team environments through a series of experiments. This chapter sets out the main findings of this program of research and the main conclusions which can be derived from these. The contributions made to knowledge are discussed along with the implications associated with these. Finally, this chapter discusses the limitations of the research before highlighting areas for further research, and finally, by providing some closing remarks.

9.2 Summary of findings

9.2.1 System Ergonomics

At the outset of the research a review of the literature was conducted. This highlighted that despite the advances made by Stanton et al. (2006a) and Salmon et al. (2009b) the literature remained divided in the perspectives offered for understanding SA. A grouping of the three main schools of thought of SA was presented and the main proposals of each were contrasted. In particular, it was highlighted that the understanding of team SA was underdeveloped and that as yet no unified definition of team SA has found favour across the research and practitioner communities. The analysis concluded that the perspectives of the Individualistic and Engineering schools of thought fell short of fully explaining team SA, as SA in these perspectives was thought to be a product of either the individual or the world. This means neither succeed in explaining the phenomenon completely as they do not take into account the interactions which take place between agents and their environment. It was concluded that the interaction perspective offered by taking a System Ergonomics approach to the study of SA, as advocated by the distributed theory of SA, was appropriate. This conclusion highlighted the need to subject the two main models of SA to an empirical test in which the assumptions set out by the literature review were examined. To this end an experiment was conducted in which the Individualistic and System Ergonomics approaches to SA, and the manner in these propose to measure team SA, was compared.

Explaining SA as either a cognitive construct residing in the mind of an individual, or as a systems phenomenon which emerges through interaction naturally leads to different measurement techniques. It was assumed that by comparing the performance of two teams organised in two very different ways that the measures of both the Individualistic and the System Ergonomics schools of thought would reveal differences between them. The qualitative and quantitative differences found when applying Social Network Analysis and Propositional Networks, measures developed within the System Ergonomics approach to assess team SA, indicate that these measures are valuable in discerning small but noteworthy differences between teams. These findings were supported by the performance data which showed differences in the sharing behaviours of the two teams, indicating that the manner in which the teams worked to solve the task did differ. The literature review and first experimental study provided a contribution to the literature by arguing that the theory of Distributed SA, in taking a systems approach, presents the most promising avenue for team SA. The publications arising from the review and study have, thus, contributed to the debate concerning team SA.

9.2.2 Distributed SA measures in team development

In light of the conclusions drawn from the literature review and the experimental study the remaining research concentrated on exploring the theory of Distributed SA in teams modeled on C2 to validate and advance the theory in the context of teams. A review of methods that were potentially relevant to assess Distributed SA was conducted. The findings suggested that methods to assess team SA can be tailored to collect data relevant to different phases of activity. The utility of combining measures was highlighted but it was recognised that this may not always be possible. Where single measures must be used they should be applied according to the phase of activity that collection of data will occur in. It was shown that the HTA may be applied before, communication analysis during and the CDM after C2 activity. The review showed that the HTA can reveal areas of interaction and emergence of Distributed SA as aspects latent to a system or team. Support can then be given to these areas where shortfalls are identified prior to activity (e.g. communication links between different team members can be strengthened). Communication analysis can reveal the teams' Distributed SA as it emerges and therefore enables a comparison between teams (Stanton et al., 2008; Stanton et al., 2009a). The CDM enables a retrospective insight into overall system awareness as it has emerged. This measure can therefore provide insight into relevant personnel's reflection on own performance and can highlight lessons learned which can be implemented in team training.

An inter-rater reliability and criterion-referenced validity study was conducted of the CDM and communication analysis. These two data collection techniques feed into the network analysis method used to assess Distributed SA. The reliability of a software tool developed to support network analysis, Leximancer™, was also considered. High levels of inter-rater reliability were found for the use of the Leximancer™ supporting its continued use in network analysis. Higher levels of validity were found for the communication data compared to the CDM. These findings suggest that the network analysis method has high inter-rater reliability when populated with communication data.

9.2.3 Organisational structure and performance

Importance has been placed on teams' role in operating safety-critical processes (Worm et al., 1998). Questions have therefore been asked with regards to whether there exists an optimal team structure. The findings presented in this thesis reveal that a relationship was established between Distributed SA and the way in which teams are organised, that is to say the organisational structure of the teams. Different organisational structures were investigated. It was found that organisational structure did affect team performance. These findings lend support to the literature which has argued that a relationship exists between organisational structure and team performance (e.g. Stammers and Hallam, 1985; Stanton, 1996; Salmon et al., 2009a; Endsley, 2000). The findings presented in this thesis indicate that some organisational structures may be better placed than others to achieve effective performance, or indeed to mitigate significant errors from occurring. In the experimental study reported in Chapter 6, the Y organisation structure appeared to be the most effective structure in terms of task performance and the development of Distributed SA. These findings therefore give support to similar studies which have argued that a relationship exists between organisational structure and team performance (Stammers and Hallam, 1985; Patrick and Morgan, 2010). Distributed SA was, furthermore, found to be strongly correlated with good task performance and moderately negatively correlated with poor task performance. This important finding indicated that teams with a higher level of relevant discussions performed better compared to teams with lower levels of relevant discussions. The relationship appears to be mediated by organisational structure. Therefore, the manner in which teams collaborate can have an impact on the emergence of Distributed SA. The relationship between SA and performance has been assumed in the literature (Salas et al., 1995; Endsley, 1995; Endsley, 1999a; Endsley, 1999b; Kaber and Endsley, 2004) but has not been shown in empirical tests. This finding therefore presents a significant contribution to the literature.

9.2.4 Transactional SA

Understanding the manner in which teams interact is of importance given the relationships found between organisational structure, Distributed SA and performance.

The findings presented in this thesis, with regards to SA transactions, revealed that transactional memory plays an important part in enabling team members to gain an understanding of what other team members know which may be of relevance to their own interdependent task. The findings revealed that more effective teams had a higher frequency of communications and transactions compared to less effective teams. A high frequency of communication, particularly at the early stages of task performance, play an important part in enabling transactional memory to develop between team members. Considering the nature of transactions it was found that a difference in the pattern of transactions existed between the more effective and less effective teams. The case study, presented in Chapter 7, showed that the quality of a team's SA transactions matter. This finding represents a case study which validates and advances the notion of transactional SA in the theory of Distributed SA. A contribution has also been made to the fields of Communication Analysis in the application of a transactional taxonomy in the context of team communication.

9.2.5 Compatible and Incompatible SA

SA transactions, having been found to impact on team functioning, were further explored to consider the nature of compatible and incompatible transactions. Ideas from Schema Theory were applied in exploring transactions in Chapter 8. In this chapter, the notion of schemata as regulators of behaviour was used to account for the workings of a team. This presents a novel framework for understanding interactions in teams.

Schemata and, in particular the process of contention scheduling, schema-driven errors and the Perceptual Cycle Model were shown to complement the ideas presented in the Distributed SA approach by explaining the way in which the previous experience and knowledge of each team member shaped their interaction with the world and wider team. The exploratory findings indicated that compatible and incompatible SA transactions appeared to be fundamental in the development and activation of schemata. Such transactions appeared to mitigate between conflicting schemata through a process of assimilation and accommodation whereby team schemata are developed. The findings indicated that the Perceptual Cycle Model can be scaled up to explain team behaviour. This presents a contribution to the field of Schema Theory and advancement of the theory of Distributed SA in terms of developing the ideas concerning compatible and incompatible SA in teams.

9.3 Advantages of the Distributed SA approach

The theory of Distributed SA opposes an individualistically and cognitively centred understanding of SA as presented by Endsley (1995). The information-processing, three-level model, of SA has received considerable attention but has arguably not been able to scale up to adequately explain team SA. As an alternative, the theory of Distributed SA draws on the ideas of Systems Theory and Distributed Cognition and in so doing offers a manner in which the interactions between individuals and their world can be assessed. This has the advantage of being able to explain the individual's contribution to team awareness whilst not discounting the elements of awareness which emerge as a result of the interactions which take place (between other team members and individuals with their environment). The Distributed SA approach therefore enables a comparison of team SA and an exploration of the process of acquiring SA. Whilst a relatively recent theory (e.g. Stanton et al., 2006a), it has received support from a number of studies (e.g. Salmon et al., 2009a; Salmon et al., 2009b; Sorensen and Stanton, 2011; Fioratou et al., 2010; Rafferty et al., 2012; Golightly et al., 2010) as well as from the research presented in this thesis which further develops the theory.

9.3.1 "Proceed with caution"

The concept of SA has not been without controversy. Flach (1995) paper "Situation Awareness: Proceed with Caution" was presented in the Human Factors special issue of SA alongside Endsley's (1995) paper in which the latter proposed the three-level model of SA. Flach (1995) argued that SA should not be "considered a causal agent" (p.149) and further stated:

> "When SA is considered to be an object within the cognitive agent, there is a danger of circular reasoning in which SA is presented as the cause of itself" (p.149).

In a similar vein Dekker (in press) argued that the:

> "stance taken by situation awareness research, as it was by information processing psychology (Wickens, 1984) is a cognitivist one: answers to how people make sense of the world are sought in presumed mechanisms of mind (Neisser, 1976)" (p.2).

Dekker (in press) referred to Flach's (1995) paper in concluding that SA research has been more about awareness, in terms of what is held in the mind of someone and how it got to be there, than about the situation itself. This pertains to a desire, according to Dekker (in press):

> "to explain human performance by reference to what goes on in the mind – how the mind forms a mirror of the world around it" (p.2).

If this angle is taken then SA research will focus on cognitive aspects of an individual, such as that seen in the short-term memory focus of the SAGAT tool (Dekker, in press, Sorensen et al., 2011; Sorensen and Stanton, 2011). This thesis has highlighted some of the issues concerned with this method and subjected it to an empirical comparison against methods used in the Distributed SA approach. Furthermore, the theoretical and empirical research underpinning this thesis highlighted that it is the individuals and their team members and environments that should be understood and analysed, as opposed to just the cognitive processes of an individual. The Distributed SA approach, therefore, take the same stance as Dekker (in press) that the operator's mind cannot be presented as a 'mirror of the world'. Distributed SA emerges from the interactions between individuals and their environment which necessitates that methods used to explore these interactions do not ignore the 'situation'.

Drawing on Flach's (1995) paper, Dekker (in press) highlighted a new caution; that SA, or the loss of it, could potentially be used to make operators criminally liable. The criminalisation of operators due to a loss of a 'construct' such as human error has been increasing in the aviation domain in recent years (Dekker, 2003). Dekker (in press) goes on to state that:

> "human factors and safety research has pretty much always been on the side of the human operator. It has tried to explain performance problems not by reference to behavioural or motivational shortcomings but to systematic relationships to the design of equipment we make people work with" (p. 4).

Indeed, it should be the role of Human Factors to highlight the challenges faced by operators and to suggest improvements to the design of systems, work processes and equipment to mitigate these challenges. In order to do so, however, all aspects of human interaction with the world must be understood and therefore the continued research into Distributed SA should be encouraged.

Distributed SA should be seen as the first steps on an 'ontological' journey, attempting to make sense of the observations which can be made of human behaviour and their sense-making of the world. This is evident in the Distributed SA approach which utilises the theories of Distributed Cognition and Systems Theory; by applying what Dekker (in press) and others (e.g. Cook and Woods, 1994; Hutchins, 1995a; Hutchins, 1995b; Stanton et al., 2006a) called:

> "a 'cognitive ethnography' to capture cognition in the wild" (Dekker, in press, p.3).

This thesis has argued that this is seen in the attempts of the theory of Distributed SA seeks to span both the realms of the mind and matter, where neither is in opposition to the other.

9.4 Limitations

In any program of research there will be a compromise between the time and resources available and the research methods used to collect and analyse data. Experiments allow for a high degree of control and internal validity but with this comes a lack of ecological validity and the findings are sometimes deemed less relevant by the individuals who might benefit from the research (Adelman, 1991). A case study approach would have allowed observation of teams in the real world but would have provided only a very small sample. Adelman (1991) consider that a large sample size enables a more:

> "precise estimate of the values on the dependent variable" (p.296).

It was felt here that experiments with a large sample were of more benefit compared to a more ecologically valid case study with a smaller sample. Larger sample sizes also enable generalisations to be made. Furthermore, the experimental task was designed with the support of a Subject Matter Expert to ensure that the task contained the essential factors from the one it was abstracted.

9.5 Further research

The research presented here has raised a number of questions which should be further explored.

9.5.1 Applications of Distributed SA

Command and control teams

Assessing the nature of teams' interactions and the manner in which this impacts performance and Distributed SA has the potential to enable a comparison of different team structures. For instance, understanding the pattern of transactions of a team which performs well in some contexts may aid the organisation of teams in a manner which supports such transactions. Research should consider the pattern of interactions and the role 'situation reports', 'requests' and 'orders' play in developing the teams' transactional memory. Research should further consider the fit between organisational structure and performance under other conditions than those applied in the experimental tasks presented in this thesis. This should be done to further explore the relationship between organisational structure and performance.

Support for the development of technology

The aim of any Human Factors theory is to support the development of better design to enhance performance and strengthen safety. Further work should consider ways in which team interactions can be supported through information technology. Research should consider how technology can support the spread of information to the right team member at the right time and the manner in which incompatibles between team members can be presented to the team. Further research should also consider how displays can support compatible SA requirements of different team members (Salmon et al., 2009b).

Team training and team work research

Assessing the quality and nature of the theory of Distributed SA and understanding the factors which impact on training to enhance team communications and interaction can be developed. Given the relationship found between organisational structures, Distributed SA and performance further research should consider training to strengthen the quality of communications. For instance, training should enable teams to utilise different types of transactions at different times of tasks and in different task environments. Further research should also seek to shed light on team work by considering the relationship between quality of communications, frequency of communications, types of transactions and team performance.

Other domains

The theories of Distributed Cognition and Distributed SA holds promise as a means by which sporting teams can enhance their game. In particular the areas of compatible SA and SA transactions can support teams, such as football teams, in reading the game as they play and enhance their awareness of each other and opponent players. Research in this domain will also provide case studies which can further develop the theory of Distributed SA (Salmon et al., 2009a).

Taking a true systems theoretic stance, recent research in the area of Distributed SA has considered the awareness held by different road users (Walker et al., in press; Salmon et al., in press). It appears that the manner in which information is used by the different road users, such as a motorcycle driver, a car driver and a pedestrian, differ. This avenue of research holds considerable promise as a means by which transport systems can be understood and improved. Exploration of the concept of Compatible SA in this context has the potential to support the development of road systems, signs and training of new road users (Walker et al., in press; Salmon et al., in press).

The system theoretic approach given by Distributed SA also has potential to support the oil and gas domain where subject matter expertise in process areas (e.g. subsea engineering, drilling and well control) is increasingly being moved to onshore control centers where sophisticated instrumentation can be monitored to predict the behaviour of wells of different installations offshore. Whilst specialist expertise can successfully be moved onshore to support several installations and different kinds of offshore operations, extraction of oil and gas remains a task which needs to be performed offshore. The integration of information onshore and offshore and the communication and coordination between the two, as well as between the different actors involved in the oil and gas extraction process (e.g. supply vessels, remote controlled vessels and helicopter transport), present an important area for further research. The advancement of the theory of Distributed SA could benefit from a large scale study combining observational and experimental methods of offshore and onshore control systems.

9.5.2 Methodological developments

The research presented in this thesis has applied a number of data collection measures and several network analysis methods to the assessment of Distributed SA. Further work should apply these and related methods such as verbal protocol analysis (Green, 1995) and ethnography (Hutchins, 1995a) to assess Distributed SA in naturalistic environments. These would present interesting case studies with which the measures applied in this program of research can be further developed. Such work should undertake to further test the reliability and validity of the measures. Methodological development should also seek to enable real-time tracing of SA transactions to capture the manner in which Distributed SA emerge during team work.

9.5.3 Theoretical advancements of Distributed SA

Further research to advance the theory of Distributed SA would be welcome. The interaction between the individual, artefacts and their environments have been categorically advocated in this thesis. Further research should seek to explore the role of technical agents, such as the manner in which technical agents update the awareness of other technical agents. Of particular interest would be a consideration of effective strategies for distributing SA across individuals and artefacts (Golightly et al., in press).

Distributed SA draws on a number of related theories (e.g. Schema Theory, Perceptual Cycle Model, Distributed Cognition and Sociotechnical Theory); however, the theory of Distributed SA could be integrated with further related theories. In the field of Human Factors the ideas presented in Resilience Engineering (Hollnagel et al., 2011), Macrocognition (Letsky et al., 2008), Accident Analysis (Salmon et al., 2011) and Naturalistic Decision Making (Klein et al., 1989) in particular have similarities with the theory of Distributed SA. In fields related to Human Factors, such as Sociology, Psychology and Organisational research, theories can be found which similarly could benefit from utilising the ideas presented in Distributed SA. Examples of theories which may benefit are the theory of Sensemaking (Weick, 1995) in Organisational research and Social Theory in Sociology (Giddens, 1987). The notions of emergence and the Distributed SA theory's analytical focus on the interaction between individuals and their environment presents advantageous manners in which behaviour in complex environments can be explained, as shown in this thesis. For all these areas the interactional approach taken by the theory of Distributed SA may lend support to the exploration and understanding of small groups, community and society at large.

9.6 Recommendations for Design

A number of recommendations for different aspects of design, from the design process to the design of artefacts, can be derived from the findings presented in this research. This section presents five main recommendations with a number of associated recommendations. Firstly, the theoretical principles underpinning the theory of Distributed SA should be taken forward in design through a comprehensive design process as outlined in the section below. Secondly, the SA requirements of each part of the system should be assessed to support design. Thirdly, displays should be designed for compatible SA and, fourthly, information architecture and navigation should be designed to support SA transactions. Lastly, teams should be designed to support Distributed SA.

9.6.1 Process of design to support Distributed SA

Designing for Distributed SA should take the lead of Interaction Design (Bolter and Gromala, 2008; Norman, 1988) and Cognitive Work Analysis (Jenkins et al., 2009a). These approaches to design argues that rather than seeking to improve how *things are* focus should be placed on imagining what *might be* (Jenkins et al., 2009a). Thinking of the purpose that a design should achieve supports the development of excellent design (Jenkins et al., 2009a; Jenkins et al., 2009b). Brehmer (2007) explained a top-down design process, drawing on Rasmussen (1985), which begins with asking the question 'why' about the system to be designed. This question seeks to define the purpose of the system (Brehmer, 2007). In military C2 systems the purpose can be defined as providing coordination and direction for military forces (Brehmer, 2007). The next step asks the question 'what' of the system which pertains to the function the system must have. In example, this design step details what a command team must do in order to fulfill the purpose of C2 (Brehmer, 2007). The last question, 'how', aims to describe the form of the system and comprises the organisation, procedures and support systems that together make up the C2 system (Brehmer, 2007). Systems are not possible to design as 'machines' because the nature of the environment the system will operate within to fulfill its purpose cannot be defined as an exact science (Brehmer, 2007). Brehmer (2007) therefore argued that the design process must identify the human functions that need to be supported and then find a form that will support these. The angle highlighted by Interaction Design and Cognitive Work Analysis and supported by Brehmer (2007), align well with the theory of Distributed SA which requires that support for SA is given at a systems level. It is recommended that the design process used to design for Distributed SA align with design processes that seek to design for the function of a system, such as those taken by Interaction Design and the Cognitive Work Analysis approached. In order to understand the function a system or teams are to fulfill the SA requirements of the team must be assessed, as outlined below.

9.6.2 SA requirements should be used to understand the function of the system

The findings of this research have highlighted the role of compatible SA as the glue which holds the team together. The different but interdependent tasks the team members hold place demands on the design of displays and artefacts. In order to inform the design of displays and artefacts to support SA Endsley (1999a) and Salmon et al. (2009b) argued that an SA requirements analysis should be performed to identify the needs of each agent. This recommendation remains valuable and it is therefore recommended that the design process begins with an assessment of the SA requirements. Specifically it is recommended that:

Use a combination of data collection techniques

It is recommended that, where possible, a combination of data collection techniques is applied. Combining methods is considered best practice in the Human Factors domain (Stanton et al., 2005). This enabled an assessment of the team, or system, to be considered during all phases of activity. As highlighted here the HTA can be applied before activity, communication analysis during and the CDM after activity has taken place. Combining the three data collection techniques to assess activity of the system before, during and after task performance can therefore be recommended for system design. Utilising the HTA can highlight where interaction between team members must occur to solve particular tasks and can thus identify challenges to be resolved through design. The communication analysis can be utilised as a means to understand the manner in which the team members interacts with other team members whilst observational techniques can be applied to assess the manner in which teams utilise artefacts in their environment. Using the CDM to retrospectively interrogate the team members can inform the findings of the preceding data collection techniques. In this way the reasoning behind the actions of the individual team members can be obtained and drawn on in the understanding of the data amassed.

Tailor the data collection to the phase of activity a team is in

Where it is not possible to utilise a combination of data collection techniques the team should be assessed utilising either the HTA, communication analysis or the CDM, in respect to the phase of activity the team under scrutiny is in.

Assess the role and use of technical agents

It is recommended that attention is given in equal measure to the artefacts individuals utilise to fulfill the function of the team. In particular different use of the artefacts must be assessed to enable a support for interdependent task performance across the team or system. This was exemplified in the finding that the pilot flying and pilot not flying utilised the instruments in the cockpit differently to perform their tasks.

Analyse the data collected using a network analysis method

It is recommended that the data collected is analysed using the network analysis method. It is further recommended that the network analysis method should from part of the design process to understand the ‘why’, ‘how’ and ‘what’ of the system (Brehmer, 2007). The communication analysis and CDM data can be analysed using a network analysis technique, such as, propositional networks or concept maps. As highlighted in this thesis, this enables a depiction of the awareness the system holds. A comparison of different phases of activity, or different teams, can then ensue to identify the SA requirements of human and technical agents.

9.6.3 Design of displays should be designed for compatible SA

Displays aimed to support teams must be able to cater for the different roles of the team members (Salmon et al., 2009b). Enabling this requires a comprehensive review of the team and builds on the SA requirements analysis. Salmon et al. (2009a) recommended that role based displays and customisable interfaces are used to support Distributed SA of different team members. The findings of this thesis show that this recommendation remains valid.

9.6.4 Information architecture should be designed for SA transactions

Information exchange has a key role in the development of Distributed SA in a team or system. As such, the means by which information can be extracted and passed around the system should be given particular attention in design. This thesis has argued, as has others (Salmon et al., 2009a), that design has focused primarily on the appearance of displays (e.g. the Engineering school of thought) and that less attention has been paid to achieving a good fit between the display and the system or team (e.g. the System Ergonomics school of thought). To achieve such a fit, the function both the system and the display have, separately and together, must be understood. This should be done through the SA requirements assessment set out above. It is further recommended that an architectural approach is taken to information where the SA requirements and team member’s roles inform the construction of information technology and lines of communication to support the distribution of transactions.

Provide customisable technology

Information technology (such as computers and PDA’s, GPS’) and telecommunication equipment (such as telephones and radios) should form part of the information architecture a system or team utilise in their work. It is recommended that the use of these is made as flexible as possible in order to support the, potentially, different use by different team members. This is in line with the notion that a systems function should guide design (Brehmer, 2007). In example, telecommunication equipment could be provided through one interface such as a touch screen with support for different communication needs. Such an interface could be stationary or portable and could enable text messages to be sent as well as have voice communication possibilities.

Design to support different transactional types

Design of information architecture (e.g. information technology and telecommunication technology) should seek to support the teams in spreading their ideas and transacting SA relevant information throughout the team. This means providing support for the different forms of transactions which were observed in the more effective teams presented in Chapter 7. 'Situation reports' were shown to reveal to other team members what one team member knows. To support this function information technology could tag messages with a category to allow team members to quickly navigate to information which provides updates on the evolving situation (e.g. 'situation reports') or that holds 'requests' from other team members. Doing so may also encourage the team to uphold a high frequency of 'situation reports', 'requests' and 'orders' which were all found to contribute to enable team members to make sense of their role and the tasks they are performing. This may also discourage 'miscellaneous' information, or "chatter" which was found to degrade performance. The goal of such designs must be to support the emergence of Distributed SA and mitigate SA breakdown. Navigating the information available through these means presents an interesting challenge for Distributed SA design and is addressed briefly below.

Navigation of information should be designed for transactions

The analyses presented here showed that here was a constant flow of information around the system. This research has argued that information should be presented in a manner which shows where the information has come from. This will increase the teams' transactional memory by allowing team members to gain an understanding of 'who knows what'. Knowing who knows what was shown to be crucial in supporting effective team performance. Stanton et al. (2006a) pointed out that the links between agents are more important than the agents themselves and effective team work depends on information transfer. Distributed SA therefore concerns itself with the use of information and its distribution between agents (Stanton et al., 2006a) Presentation of where information originates from and how it has been built upon with additional information can support team members in navigating information. This can be particularly important for teams operating in complex environments, such as C2 where information overload presents a challenge and where information can often be incomplete or even conflicting (Patrick and Morgan, 2010).

9.6.5 Teams should be designed to support Distributed SA

Organisational structure was found to be associated with task performance and mediates the relationship found between Distributed SA and performance. The manner in which teams are organised should therefore be carefully considered as teams utilise the structure they are in to communicate and complete tasks. This thesis has argued that teams' ability to engage with and adapt to their environment are closely linked to Distributed SA. Team organisation has furthermore been found to impact on communication in the team (Stammers and Hallam, 1985). Constraints placed on the team structure translate to constraints placed on information flow, as concluded in Chapter 6. Lack of constraints, however, where an organisation where every team member can communicate with everyone else and where roles and authorities are poorly defined, do not necessarily give effective performance (Stanton et al., 2010b; Stanton et al., 2011b). Optimal structure depends on the interactions which the team must engage in. This means that different structure may be suited to particular environments and classes of tasks (Alberts and Hayes, 2003; Alberts and Hayes, 2006; Stanton et al., 2010b; Stanton et al., 2011b). It is recommended that teams are designed to be able to adapt dynamically to changing circumstances. This can be done through team training and procedures. The manner in which teams communicate can also be constrained and thereby altering the structure of the team. Designing in this manner pertains to the 'how' question of the design process described by Brehmer (2007).

9.7 Closing remarks

I came to begin my doctoral programme with a strong interest in Human Factors and a number of unanswered questions with regards to team work. In particular, I was interested in what makes a set of individuals work together, interdependently, towards a common goal. In so doing exceed the performance of single individuals in domains such as surgery, military command and control and sports whilst negating a dynamic and changing environment. What was the key to successful team performance? I was initially drawn to the phenomenon of SA through the theory of SA presented by Endsley.

I have learned through this research that SA is a meaningful concept with which to understand and compare teams in terms of their inner workings. Whilst not a causal factor in ensuring that all teams who have Distributed SA perform well, this research have shown that Distributed SA is strongly associated with performance and that this is mediated through the structure of the team. In other words, the manner in which the team is coordinated and communicates. This chimes with the work of others, most notably Stanton et al. (2006a) and Salmon et al. (2009b) whose research inspired my own. Where Endsley's model first caught my attention, Stanton and Salmon's model of Distributed SA paved the way for this programme of research and my continued interest.

Encouragingly, this research has shown that a systems perspective on SA enables insights into the factors which guide successful teamwork. It is therefore my hope that this thesis contribute to the wider application of the systemic approach to understand teams operating in complex environments in a broad sense, and for the assessment and support of SA in particular.

In ending, it is my sincere hope that this thesis may have made a contribution to the debate which persists in relation to the nature of team SA and its applicability in complex environments. It is my desire that this thesis is taken as an advancement and support of the theory of Distributed SA, and that my work in turn can inspire other researchers to further advance its measurement and application. Doing so will enable further understanding of teams so that ultimately the teams and organisations within which they operate may benefit.

10 Related papers published by the author

10.1 Peer-reviewed published papers

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10.2 Conference papers

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10.4 Papers submitted for peer-review

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