Developing Guidelines for Distributed Teamwork: Review of the Literature and the HFI DTC's Distributed Teamwork Studies

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1 Executive Summary

1.1 Background and reasoning behind the work

Distributed teams are increasingly being employed within complex systems and rapid technological advances are affecting the ways in which they work and can potentially work. Despite this, guidance on how distributed teams should work, how they should be organised and trained, what communications technology they should use and how support systems should be designed is not readily available. This report presents, based on a review of the relevant literature and also a series of naturalistic case studies undertaken previously by the HFI DTC, a series of initial guidelines on how teams, systems, technology and procedures should be designed and organised in order to enhance distributed team working performance.

1.2 Specific research question being addressed

Specifically, this research attempts to address the question of how distributed teamwork can be facilitated through system, procedure, training and team design.

1.3 What was undertaken in the research?

The research involved reviewing the literature on distributed teams and the HFI DTC's previous studies on distributed teamwork, in order to formulate a series of guidelines designed to enhance distributed teamwork performance.

1.4 What was discovered?

The literature indicates that, despite offering some significant advantages over and above co-located teams, there are various problems (e.g. degraded teamwork behaviours) associated with the use of distributed teams. The literature also suggests that, despite the fact that distributed teams are likely to become the dominant form of team interaction, relatively little is known about neither distributed teams nor about what measures can be taken to enhance distributed team performance.

Encouragingly, previous work in the area (by others and the HFI DTC) provides insights into how distributed teamworking systems can be designed so that performance is enhanced. Various elements of distributed teamworking systems, including the tasks being performed, the procedures and technologies being used, and the information passed between team members, can be designed to that distributed teamworking performance is supported and not hindered.

1.5 Main conclusions and recommendations

A series of guidelines for enhancing distributed team working performance are proposed based on the literature and case study reviews. The guidelines are meaningfully organised under the headings of *task* (i.e. the characteristics of the tasks undertaken by the team), *social* (i.e. the organisation of the team and the communications links between them) and *knowledge* (i.e. the information used by and passed around the team) network guidelines. The guidelines specify, based on the findings from previous studies in the area, ways in which the task, social and knowledge networks used can be organised so that distributed teamwork performance is supported and not hindered in anyway.

For example, the literature and case study evidence suggests that the characteristics of the tasks being performed can either facilitate or inhibit team performance. Thus guidance regarding tasks performed by distributed teams is specified, including designing tasks to facilitate co-ordination, ensuring that roles and responsibilities are clearly defined, using loosely coupled tasks, ensuring appropriate allocation of functions between team members and between team members and technology, optimising team member workload and ensuring that team members engage in performance monitoring and back-up behaviours.

The social network guidelines reflect how the team is organised and how and what communications take place between team members. Guidance in relation to the social network adopted includes to ensure that well defined and appropriate communication strategies (e.g. closed loop communications) are used, providing appropriate and explicit communications links between team members, ensuring that the team has appropriate and effective leadership, promoting the establishment of common ground between team members, ensuring that information flow is maintained, promoting and ensuring high levels of trust between team members and between team members and the technology that they use, selecting appropriate communications media for the tasks and communications required, and training distributed teams together in a contextually relevant environment.

The knowledge required for task performance is directly related to the team's level of situation awareness. Facilitating the generation and maintenance of appropriate levels of situation awareness is all about ensuring that the right information can be communicated to the right team members at the right time. Accordingly, the guidelines regarding the knowledge network of distributed teams includes clearly defining the information requirements of the different team members, supporting the compatible and transactive situation awareness requirements of different team members, promoting the development of shared mental models between team members, promoting meta situation awareness between team members, using multiple technologies to support multiple team member roles and goals, and ensuring that technologies distribute and present information accurately and in a timely manner.

It is recommended that, when designing distributed teamworking systems, procedures, technologies and/or training programs, the guidelines presented in this report are considered. Further, it is recommended that further investigation be undertaken in the area, and that additional guidance for the design of distributed teamworking systems be specified.

1.6 Military relevance of the work

The use of distributed teams is common within the military domain and is likely to increase significantly in the future. This report presents a series of initial guidelines, developed based on the distributed teamwork literature and naturalistic case study evidence, which can be used to enhance the performance of distributed teams in military environments.

2 Introduction

2.1 Introduction

The use of distributed teams has increased significantly in recent times (Fiore, Salas, Cuevas & Bowers, 2003). Further, as increases in technological capability continue, the presence of distributed teams within complex systems is likely to increase significantly (Fiore et al, 2003). Although distributed team working brings with it many advantages, it also presents unique challenges to system, technology, training and procedure designers, and the characteristics of distributed teams are such that inappropriately configured systems can lead to significant performance decrements. Despite this only relatively little is known about distributed teams (Bell & Kozlowski, 2002; Fiore et al, 2003) and there is little guidance available on how to enhance distributed team working in complex systems.

The aim of this report is to present, based on a review of the teamwork literature and on the findings derived from a series of previous HFI DTC case studies on distributed teams in the military and civil domains, a set of initial guidelines on how teams, systems, technology and procedures should be organised in order to enhance distributed teamwork performance.

2.2 Structure of report

The following three tasks were undertaken as part of this research:

1. Review of the teamwork and distributed teamwork literature. A review of the teamwork and distributed teamwork literature was undertaken in order to increase our understanding of distributed teams and also to identify existing principles and guidelines for distributed teamwork.

2. Review of the HFI DTC's previous distributed teamwork studies. A review of the HFI DTC's previous studies on distributed teams was undertaken in order to identify the characteristics associated with successful distributed teamwork performance.

3. Development of initial guidelines for distributed teamwork. Based on the findings derived from the first two tasks a series of initial guidelines for enhancing distributed team performance were developed.

This report presents a summary of the work undertaken and the findings derived from this research. A summary of the literature review on distributed teams is presented in chapter three, following which the summary of the HFI-DTC's previous studies on distributed teams is presented in chapter four. The guidelines for distributed teamwork, derived from the literature and case study reviews, are presented in chapter five. Finally, the conclusions derived from this research are presented in chapter six.

3 Teams & Distributed Teams

3.1 Teams

3.1.1 Introduction

The use of teams has increased significantly over the past three decades (Savoie, cited in Salas, 2004), primarily due to two factors; firstly, the increasing complexity of work and work procedures and, secondly, because appropriately trained and constructed teams can potentially offer a number of advantages over the use of individual operators, including the ability to better perform more difficult and complex tasks, greater productivity and improved decision making (Orasanu and Fischer, 1997), more efficient performance under stress (Salas & Cannon-Bowers, 2000) and a reduction in the number of errors made (Wiener, Kanki & Helmreich, 1993; cited in Salas & Cannon-Bowers, 2000).

3.1.2 Teams defined

A team is characterised as consisting of two or more people, dealing with multiple information sources and working to accomplish a shared or common goal of some sort; Salas, Prince, Baker and Shrestha (1995) define a team as "a distinguishable set of two or more people who interact dynamically, interdependently and adaptively toward a common and valued goal, who have each been assigned specific roles or functions to perform and who have a limited life span of membership". Teams have a range of distinct characteristics that distinguish them from small groups; Salas (2004), for example, suggests that characteristics of teams include meaningful task interdependency, co-ordination among team members, specialised member roles and responsibilities, and intensive communication. Paris, Salas & Canon-Bowers (2000) suggest that team characteristics include multiple sources of information, task interdependencies, co-ordination among team members, common and valued goals, specialised member roles and responsibilities, task relevant knowledge, intensive communication and adaptive strategies for responding to change.

3.1.3 Teamwork

Collaborative work comprises two forms of activity: teamwork and taskwork. Teamwork refers to those instances where individuals interact or co-ordinate behaviour in order to achieve tasks that are important to the team's goals (i.e., behavioural, attitudinal, and cognitive responses co-ordinated with fellow team members), whilst taskwork (i.e., task-oriented skills) describes those instances where team members are performing individual tasks separate from their team counterparts i.e. those tasks that do not require interdependent interaction with other team members (Salas, Cooke & Rosen, 2008). Teamwork is formally defined by Wilson, Salas, Priest and Andrews (2007) as "a multidimensional, dynamic construct that refers to a set of interrelated cognitions, behaviours and attitudes that occur as team members perform a task that results in a coordinated and synchronised collective action." According to Glickman, Zimmer,

Montero, Guerette, Campbell, Morgan, and Salas (1987; cited in Burke, 2004) team tasks require a combination of taskwork and teamwork skills in order to be completed effectively.

3.2 Models of teamwork

There have been many attempts to postulate models of teamwork (e.g. Flieshman & Zaccaro, 1992; Helmreich & Foushee, 1993; McIntyre & Dickinson, 1992; Morgan et al, 1986; Olmsted, 1992; Salas, Sims & Burke, 2005; Zsambok, Klein, Kyne & Klinger, 1993 etc.), far more than there is room to include here (a recent review by Salas, Sims and Burke (2005) identified over 130 models). Most of the models presented in the academic literature attempt to define the different teamwork processes involved and also the different attributes that teams possess. A summary of the more prominent teamwork models presented in the literature is presented in Table 3-1.

Table 3-1. Summary of teamwork models.

Teamwork Model	**Teamwork behaviours/processes**
Normative Model of Group Effectiveness (Hackman, 1987)	Group design Group synergy Organizational variables Team strategies Effort by team Team knowledge and abilities
Big 5 Teamwork Model (Salas, Sims & Burkes, 2005)	Team leadership Team orientation Mutual performance monitoring Back up behaviour Adaptability Shared mental models Closed loop communication Mutual trust
Sociotechnical Systems Theory Perspective (Pasmore, Francis, Haldeman & Shani, 1982)	Task interdependencies Task requirements Organisational context Team design Shared mental models Team effort Task strategies Team knowledge Team skills Common goals
Team Performance Model (McIntyre & Dickinson, 1992)	Orientation Leadership Communication Feedback Back up behaviour Monitoring Coordination
Teamwork Model (Flieshman & Zaccaro, 1992)	External conditions Member resources Team characteristics Task characteristics Individual task performance Team performance function

For example, Salas et al (2005) outlined the big five model of teamwork, arguing that the five most important teamwork processes are: leadership, mutual performance monitoring, back up behaviour, adaptability and team orientation. Salas et al suggested that these factors would improve performance in any team, regardless of type, so long as three supporting mechanisms were also present within the team: shared mental models, closed loop communication and mutual trust.

Team competencies are also heavily discussed within the teamwork literature. Salas & Cannon-Bowers (2000) define team competencies as resources that team members draw from in order to function; they refer to what team members need to know, how they need to behave and what attitudes they need to hold (Salas, Cannon-Bowers, & Smith-Jentsch, 2001; cited in Salas, 2004). Knowledge-based competencies refer to what team members 'think' during team work performance; Salas & Cannon-Bowers (2000) suggest that knowledge-based competencies refer to the necessity of understanding facts, concepts, relations, and underlying foundations of information that a team member must have to perform a task; they cite cue-strategy associations, team-mate characteristics, shared mental models and task sequencing as examples of knowledge-based competencies. Skill-based competencies refer to the things that team members 'do' during team work performance and, according to Salas & Cannon-Bowers (2000), are the necessary behavioural sequences and procedures required during task performance. Examples of skill-based competencies include adaptability, situational awareness, communication and decision making (Salas & Cannon-Bowers, 2000). Attitude-based competencies refer to what team members 'feel' during teamwork performance and are those affective components that are required during task performance (Salas & Cannon-Bowers, 2000). Examples of attitude-based competencies include motivation, mutual trust, shared vision, teamwork efficacy and collective orientation.

3.3 Distributed teams

The majority of the literature surrounding teams and teamwork focuses on conventional co-located teams; however, the use of distributed teams, also known as virtual or geographically distributed teams, is expanding rapidly (Fiore et al, 2003). A distributed team is one whose members are dispersed over different physical locations but are connected by communications technology of some sort; they comprise geographically separated agents working together on the same task. Distributed teams have been formally defined as "teams whose members are dispersed across distance and time, are linked together by some form of electronic technology, and physically interact with each other rarely or not at all" (Sessa, Hansen, Prestridge & Kossler, 1999, p.10). Co-located teams, on the other hand, are defined as "teams typically operating in the same location with close physical proximity, whose members can have face-to-face contact on a regular basis" (Sessa et al 1999, p.10).

The main differences between co-located and distributed teams relates to the physical separation between team members and the interactions between team members. In a distributed team, team members are distributed spatially from one another and subsequently use technology to mediate their interactions with one another. Bell & Kozlowski (2002), for example, suggest that the main differences between the two are the proximal locations of team members and the technology used to mediate communications

(see Figure 3-1). According to Sessa et al (1999), distributed teams differ from conventional face-to-face teams in two main ways. Firstly, the medium on which the two kinds of teams depend on differs. Co-located teams typically operate in a same time, same place environment and use the medium of face-to-face meetings, whereas distributed teams do not operate in the same place and thus rely heavily on information and communications technologies including video-conferencing and audio-conferencing tools, e-mail, telephone, fax, whiteboard and the Internet (Sessa at al, 1999). Secondly, Sessa et al (1999) also point out that, because of the physical separation and reliance on technology, team processes, such as communication and co-ordination, are more difficult to achieve for distributed teams.

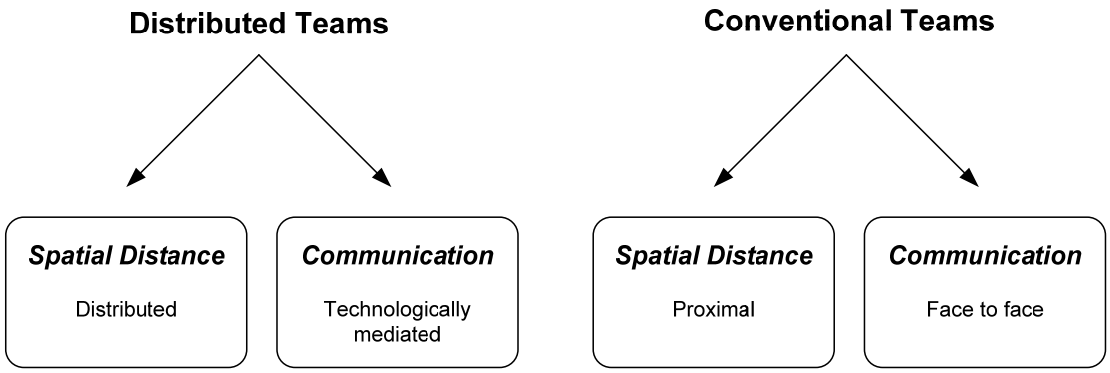


Figure 3-1. Distributed versus conventional teams.

Within a distributed team, members might have different information, expertise, resources and responsibilities, as well as different knowledge of individual sub-problems (Kleinman et al, 1992; cited in Salas et al, 2001). Salas et al (2001) described five main characteristics of distributed teams along with the challenges to teamwork that they pose (See Table 3-2).

Table 3-2. Characteristics of distributed teams (adapted from Salas et al, 2001).

Characteristic	*Effect on Team*	*Task Performance Requirement*
Loss of visual cues	• Degraded communications	• Task communication that builds situation awareness • Use of implicit co-ordination during task execution
Restricted information flow	• Fewer communications	• Task communication that builds situation awareness • Use of standardised communication formats • Use of implicit co-ordination during task execution
Lack of immersion	• Reduced situation awareness	• Build in task cues to prompt other team members • Teamwork processes such as back-up behaviour and monitoring • Trust
Electronic communication	• Less verbal cues; harder to interpret actions	• Teamwork processes such as back-up behaviour and monitoring • Trust
Multi-cultural	• Degraded communications • More difficult to manage meanings, beliefs and attitudes	• Use of closed loop communications • Task communication that builds situation awareness

Bell & Kozlowski (2002) suggest that the differences between distributed and conventional teams go further than merely the lack of face-to-face interaction within a distributed team. They suggest that although the tasks faced by both forms of team are often the same in nature, it is the ways in which they go about accomplishing the tasks and the constraints that they face that are the main differences between the two.

The reliance on technological means to facilitate teamwork is therefore one of the main facets of a distributed team; Cuevas, Costello, Bolstad & Endlsey (2006) point out that, unlike traditional co-located teams, distributed teams must co-ordinate their efforts across both time and space, relying primarily upon technology-mediated communication channels to accomplish their goals. A variety of tools and techniques exist for supporting distributed teams; these include, amongst others, video and audio conferencing tools, telephones, radios, email, instant messaging systems (e.g. MSN Messenger), collaborative whiteboards/smartboards, and groupware tools. According to Cuevas et al (2006) the utility of each approach is ultimately dependent upon the task, the situational constraints and also the team's composition.

Although ostensibly models of teamwork (e.g. Salas et al, 2005) still apply to distributed teams, there have been recent attempts to prescribe models of distributed teamwork. Fiore et al (2003), for example, presented a model of distributed teamwork. An adaptation of the model is presented in Figure 3-2.

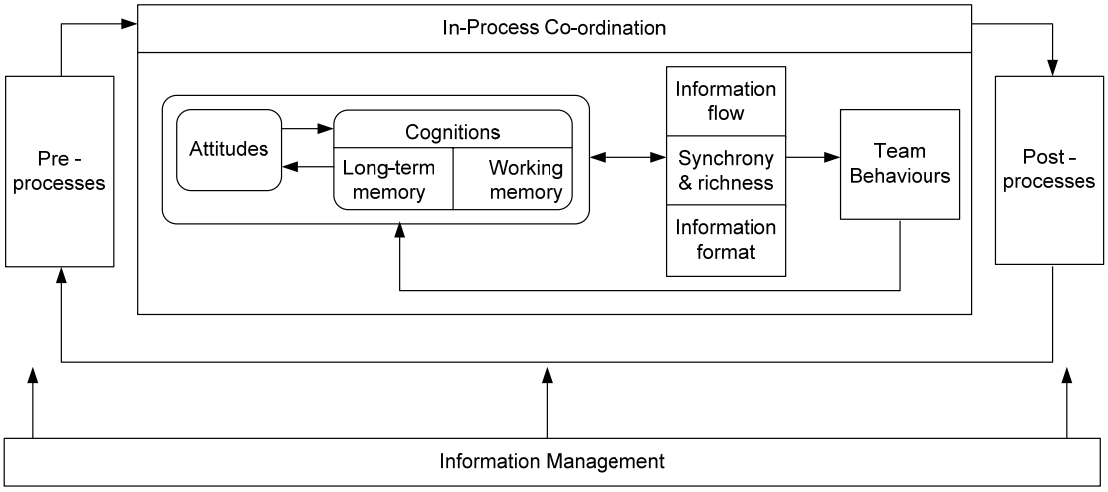


Figure 3-2. Distributed co-ordination space (adapted from Fiore et al, 2003).

Fiore et al's generic model (2003) focuses on the attitudes, behaviours and cognitions of distributed teams and consists of three inter-related constructs; team attitudes or socio-cognitive factors, technology enabled interaction, and dynamic processes associated with distributed team interaction. According to the model, distributed teams have three phases of interaction; pre-process interaction, in-process interaction and post-process interaction. The model therefore suggests that team behaviours are not only of interest during teamwork process, but also that teams exhibit antecedent and consequent behaviours (Salas et al, 2001); behaviours across all three phases are critical to team processes. Further, the model suggests that information flow, synchrony and richness and information format are important factors in the quality of the distributed teamwork.

Distributed teams offer various benefits over and above conventional co-located teams. Distributed teams allow organisations to become more flexible, adaptive and responsive (Bell & Kozlowski, 2002), organisational flexibility in meeting goals is expanded (Fiore et al, 2003) and the distribution of tasks across different locations increases the reach and presence of the team and allows team members to work in parallel and accomplish tasks quicker. Perhaps of more concern to this research, however, are the various problems associated with the use of distributed teams; Salas et al (2001), for example, suggest that distributed teams have fewer (due to restricted information flow) and degraded (due to loss of visual cues) communications, reduced situation awareness (due to lack of immersion) and find it more difficult to interpret actions and manage meanings, beliefs and attitudes. Fiore et al (2003) describe the concept of team opacity, arguing that the distribution of team members decreases awareness of other team member actions, since the environment becomes data lean and primarily cognitive. Paris, Salas & Cannon-Bowers (2000) suggest that greater distances between team members exert a negative influence on communications and cohesiveness. The acquisition and maintenance of distributed situation awareness (Salmon et al, 2008; Stanton et al, 2006) is also more difficult in distributed teams. For example, Sonnenwald, Maglaughlin & Whitton (2004) point out that when team members are distributed geographically, many of the physical cues that help create and maintain situation awareness are absent. The corollary of this is that team members are dependent upon technology to mediate situation awareness (Sonnenwald et al, 2004).

Other problems have also been articulated; co-ordination decrement, which refers to a drop in the productivity of teams (also known as process loss), has been found to occur at greater levels within distributed teams (Fiore et al, 2003). Team adaptability may also be affected as response times are likely to be increased when members are distributed, which will lead to a slower process of adaptability. Team cohesion may be harder to develop in distributed teams due to the lack of cues available, such as paralinguistic cues, which have been proven to facilitate impression formation. Team co-operation may also be affected by the distribution of teams as co-operation is affected by mutual trust between team members; thus co-operation may be dependent on members' ability to predict and depend on their team members' behaviours. Mutual trust and adequate predictions may not be as accurate in distributed teams. Trust has been said to affect co-ordination, co-operation and helping within teams, as well as mediating the degree to which team members share ideas and opinions (Fiore et al, 2003).

3.4 Studies on distributed team working

Despite their prevalence in modern day systems, only relatively little research focusing specifically on distributed team performance has been undertaken (compared to the wide body of research focusing on conventional teams). A summary of the research discussed in the academic literature is given below.

Most of the work on distributed teams has focused either on the impact that different technologies have on distributed teamwork performance, or on the teamwork behaviours exhibited by distributed teams. Cuevas et al (2006), for example, investigated the impact of different technologies on distributed team communication and performance. They found that teams communicating face-to-face or using voice telephone had almost twice as many communication exchanges as teams using instant messenger and also expressed more requests for confirmation and provided more acknowledgements of communications received. Further, compared to teams using face-to-face or telephone, teams who used instant messenger took longer to complete all tasks and perceived them to be more difficult. Cuevas et al (2006) concluded that the negative effects of text-based collaboration techniques cannot be mitigated by the use of synchronous information flow.

Carletta, Anderson & McEwan (2000) studied the effects of communications technology on distributed teams and found that it impacted turn taking and also the degree of social presence that group members feel; the less real-time and multimedia offered by a particular technology, the more distant team members are likely to feel; on the contrary, the distance between team members may reduce inhibitions and make them more likely to offer their opinion.

Stanton, Connelly, Prichard & van Vugt (2002) conducted an experimental study of technologically mediated command and control activities focusing on the effects of location of team members, communication medium and type of command and control task on the performance of the team (Stanton et al, 2002). Their findings demonstrated that all of these variables interact, such that some tasks are better performed remotely whilst others are performed better face-to-face, and that some tasks are better suited to one communication medium over another.

Klein & Miller (1999) used observational study and critical incident interviews to study five different types of distributed planning teams from different military domains. Klein & Miller (1999) observed instances where battalion commanders realised that their plan was not working but, due to the number of different, distributed elements to be informed of any changes chose to continue with the plan rather than modify it. In conclusion Klein & Miller (1999) identified a series of forcing functions likely to impact distributed planning.

Table 3-3. Forcing functions impacting distributed team planning (adapted from Klein & Miller, 1999).

Forcing functions impacting distributed planning

External factors
- Scarcity of resources
- Time pressure
- Uncertainty
  - Missing information
  - Unreliable information
  - Ambiguous/conflicting information
  - Complex information
  - Instability of the environment
Internal factors
- Technology
- Expertise available for performing the planning
Task-related factors
- Ill structured task
- Need to produce a plan that can be quickly modified
- Redundancy

Various studies suggest that the way in which information is distributed within a team affects its performance (Artman, 2000). Brehmer & Svenmarck (1995; cited in Artman, 2000) compared the ability of teams to control a dynamic system. In comparing a hierarchical information distribution architecture and a fully connected information distribution architecture (where every agent can communicate with one another), they found that the hierarchical condition enabled the system to be controlled better (although this was only marginally better).

In reviewing a decade of work in their lab's research into distributed teamwork within the paradigm of Computer Supported Collaborative Work (CSCW), Olson and Olson (2004) concluded that the "death of distance" (Cairncross, 1997) has been overstated. Drawing upon data concerning productivity levels in software engineering and design, Olson and Olson contend that there is often a significant price to pay in abandoning co-location for geographic dispersal of workers. Indeed, significant productivity gains were also noted in cases where 'maximum co-location' in 'project rooms' or 'war rooms' was used suggesting that even a corridor or an office door can constitute distance (for similar empirical results see Espinsoa et al., 2002). However, the authors did identify four sociotechnical factors that may mitigate the negative effects of distance. First, establishing common ground

between workers. The concept of common ground describes that which is required for workers to communicate meaning efficiently and accurately. This can range from elements in the worker's background (e.g., common background knowledge, practice and technical language) to aspects of high common ground established within a single conversation. In general the more cues that collaborative technology makes available the better common ground can be established, particularly in groups that may begin with relatively little in common; video may for example allow pointing and gestural communication; voice as compared with text allows some possibility of awareness of the speaker's mental state and use of rhetoric, humour and so on through tone of voice. These conclusions are also broadly shared by Espinosa et al. (2002) who carried out a multi-method investigation of their own empirical studies and archival studies. Their findings emphasised the importance of familiarity with the subject matter of work and similar background knowledge in co-ordinating work in distributed teams. These findings suggest that as a rule of thumb, the bandwidth allocated to communications should be an inverse function of the degree of pre-existing common ground between participants. A corollary of this relevant to military contexts, where bandwidth may be a tightly limited commodity, is that establishing common ground prior to field operations may serve to reduce the bandwidth requirement.

The second factor identified by Olson and Olson is that of coupling in work. A drawback of distributed team working is that tightly coupled work (where the tasks individuals perform are highly dependent on the work of others) is difficult to do, as there is an increased requirement for rapid and frequent interaction between workers. If this requirement is not met, it can result in either delays or mistakes being made. Thus where possible for distributed work, loose coupling between tasks is preferable. This would also appear to suggest that, where distributed tightly coupled work is required, a significant communications bandwidth requirement should be anticipated. The final two factors, collaboration readiness and technology readiness, relate to attitudes held by workers to distributed working; if workers are either unwilling to collaborate - where for example there is a tangible or intangible incentive towards not sharing knowledge or work with others - or unwilling or unable to use the technology itself then this clearly precludes any possibility of effective distributed work. One limitation of these CSCW-oriented studies of distributed work is that they tend to discuss primarily software engineering activities that are abstract in nature and have no inherently geographical element, whereas in a military context teams are often distributed because the nature of the tasks they are undertaking are themselves geographically distributed and more likely to be concerned with concrete matters.

Caldwell & Everhart (1998) examined the performance of distributed supervisory control teams on a navigation task in a multi-level tank simulation. They found that, for the task analysed, the number of words exchanged between team members was a significant covariate factor affecting team performance. Caldwell & Everhart (1998) concluded that there is a critical need for synchronous information flow for effective real-time performance in distributed teams, and that greater information synchronisation and communications flow between team members is required for effective distributed team performance.

3.5 Summary

Distributed teams comprise geographically dispersed team members who are connected by communications technology of some sort. Although they offer some significant advantages over and above co-located teams, research has identified various problems (e.g. degraded teamwork behaviours) associated with their use. The literature indicates that, despite the fact that distributed teams are likely to become the dominant form of team interaction (Fiore et al, 2003), relatively little is known about distributed teams nor about what measures can be taken to enhance distributed team performance. From the studies focusing on distributed teams presented in the literature, the following conclusions can be made:

- Distributed teams typically use fewer communications than co-located teams (e.g. Cuevas et al, 2006);
- Communications in distributed teams are degraded due to a lack of visual cues;
- Information flow is often reduced in distributed teams;
- There is often a lack of team member presence in distributed teams;
- The quality of distributed team task performance is highly dependent upon the type of task being performed; co-located teams, for example, tend to perform better on judgemental and visual tasks (Stone & Posey, 2008);
- There is a need for synchronous information flow between distributed team members;
- Increased information synchronisation and information flow leads to effective distributed team performance;
- Tightly coupled tasks are more difficult for distributed teams; and
- Common ground is required for effective distributed teamwork.

4 Case Studies on Distributed Teamwork

4.1 Introduction

The literature review presented in the previous chapter indicated that there has only been relatively little investigation into distributed team working; further there is very little in the way of guidelines to support or enhance distributed teamwork performance. The purpose of this chapter is to review the HFI DTC's previous studies on distributed teams in order to identify some common features of distributed teamwork that can be used to aid the development of such guidelines.

4.2 HFI DTC studies on distributed teams

The HFI DTC consortium has been involved in the conduct of various naturalistic studies focusing on distributed teamwork in a number of complex military and civil domains; these include the land warfare (Salmon, Jenkins et al, 2007; Stanton et al, 2008; Walker et al, 2005), multinational warfare (Verrall, 2006), airborne early warning and control (Stewart et al, 2008), naval warfare (Salmon, Stanton et al, 2007; Stanton et al, 2006), air traffic control (Walker et al, 2006), railway maintenance (Walker et al, 2006), energy distribution (Salmon et al, 2008) and emergency services (Houghton et al, 2006) domains. These studies involved applying the Event Analysis of Systemic Teamwork methodology (EAST; Stanton, Salmon, Walker, Baber & Jenkins, 2005) or the Workload, Error, Situation awareness, Time and Teamwork modelling tool (WESTT; Houghton, Baber & Cowton, 2005) to naturalistic distributed teamwork scenarios.

4.2.1 EAST & WESTT

Underpinning the EAST and WESTT approaches is the notion that distributed teamwork can be meaningfully described via a 'network of networks' approach; to this end they analyse teamwork from three different but interlinked perspectives, the *task*, *social* and *knowledge* networks that underlie teamwork activity. Task networks represent a summary of the goals and subsequent tasks being performed within a system, social networks analyse the organisation of the team and the communications taking place between the agents working in the team, and knowledge networks describe the information that the agents use and share in order to perform the teamwork activities in question. This so-called 'network of networks' approach to understanding collaborative endeavour is represented in Figure 4-1 (adapted from Houghton, Baber & Cowton, 2005).

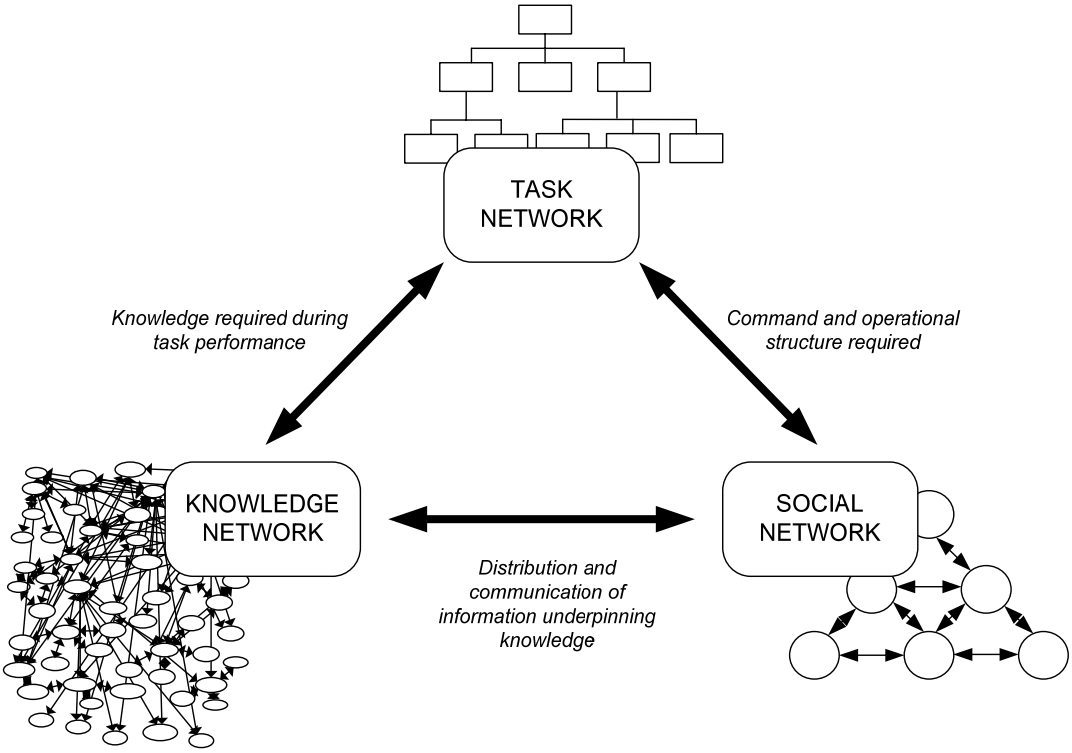


Figure 4-1. Network of networks approach to analysing distributed teamwork; figure shows example representations of each network, including Hierarchical Task Analysis (task network), social network analysis (social network) and propositional network (knowledge network) representations.

The EAST and WESTT approaches use a combination of human factors methods to produce these networks; Hierarchical Task Analysis (HTA; Stanton, 2006) is used to construct task networks, social network analysis (Houghton et al, 2006) is used to construct and analyse social networks, and propositional networks (Salmon et al, 2008) are used to construct and analyse knowledge networks.

In order to inform the development of guidelines designed to enhance distributed team working performance, a review of the HFI DTC's previous EAST and WESTT-based investigations was undertaken. The purpose of this was to use the findings derived from these studies, along with the contemporary literature, to formulate a series of initial guidelines. A summary of the studies focused on is presented in Table 4-1.

Table 4-1. Summary of distributed team working case studies undertaken by the HFI DTC.

Study	Summary of Main Findings	Implications for Distributed Teamworking
Domain: Energy distribution **Scenario(s):** Naturalistic maintenance scenarios **Summary:** EAST approach used to analyse three energy distribution maintenance scenarios **Reference:** Salmon et al (2008)	• Dense network with high level of communications between agents involved; • Distributed situation awareness comprised each agent's compatible view on the situation; • Efficient team performance down to four key factors: - Well defined roles and responsibilities - Clear communications links - Procedures dictate continuous level of information flow - Appropriate network structures	• Communications links are key element; communications links should be appropriate, explicit and open at all times; • Ensure that roles and responsibilities are well defined and understood by all; each team member should be aware of their own and other team member's roles; • Use procedures to dictate continues information flow between distributed team members.
Domain: Land warfare **Scenario(s):** Land warfare planning and battle execution scenarios **Summary:** Involved analysis of land warfare electronic mission support system during an operational field trial **Reference:** Stanton et al (2008)	• Electronic system fails to support the different situation awareness requirements of its different users; • Electronic system fails to adequately support distributed planning; • Information presented by the electronic system was often inaccurate and was not often presented in a timely manner; • Electronic system has created the need for a new role within organisation; • Overall, the system (in its present format) does not improve command and control	• Systems to support distributed team working should cater for the different roles and information/tool requirements of the different users working within the system; • Information presented by support systems needs to be timely and accurate.
Domain: Naval warfare **Scenario(s):** Type 23 Frigate training scenarios **Summary:** EAST approach was used to analyse a series of Principal Warfare Officer (PWO) training scenarios undertaken in a Type 23 Frigate simulated control room **Reference:** Stanton et al (2006)	• Clear hierarchy involved in teamwork; • Distributed team situation awareness comprises activated information elements; these activations change over the course of a mission; • Distributed team working systems have a network of linked information elements; the system owns this information network and the individual team members each have different views of the network; • It is important for team members to have awareness of who holds what view and to interpret the usefulness of information that can be passed around in light of these different views; • Network links more critical than nodes themselves in maintaining distributed situation awareness; effective teamwork is dependent upon information transfer across network links	• Communications links are key element; communications links should be appropriate, explicit and open at all times; • Team members need to know which communications links to use and when; • Ensure that roles and responsibilities are well defined and understood by all; each team member should be aware of their own and other team member's roles; • Team members need to be cognisant of what other team members should know during task performance.
Domain: Naval warfare **Scenario(s):** Confederated and federated coalition task group training scenarios **Summary:** EAST approach was used to analyse a series of confederated and federated coalition task group training scenarios; the analysis was undertaken in order to identify the most suitable form of training for future naval warfare groups **Reference:** Salmon, Stanton et al (2007)	• Significant differences between training systems analysed; • Confederated training system better for training on collaborative activities and communications technologies; • Shared mental models only enhanced in combined confederated and federated training system; • Combined federated and confederated training system produces richer distributed team situation awareness; • Combined confederated and federated training system offers the most training benefit for distributed teams.	• Distributed teams should be trained together in a common environment; it is more appropriate to train all elements of the team together in a common environment than to train parts in isolation.

Table 4-2. (Table 4-1 continued).

Study	Summary of Main Findings	Implications for Distributed Teamworking
Domain: Air Traffic Control **Scenario(s):** Naturalistic air traffic control scenarios **Summary:** EAST approach used to analyse air traffic control scenarios **Reference:** Walker et al (2006)	• ATC operations facilitated by seven forms of communications media; • Complexity is spread across agents via hierarchical sub-division of teams; • Peer to peer architecture allows fast response in during high tempo situations.	• Network organisation has key role in team's performance; • Careful consideration should be given to the appropriate communications media; • System design should consider the different modes of distributed team working; certain technology may be appropriate for one configuration, but inappropriate for another;
Domain: Railway maintenance **Scenario(s):** Naturalistic railway maintenance scenarios **Summary:** EAST approach used to analyse three railway maintenance scenarios **Reference:** Walker et al (2006)	• Complexity in this case arose due to requirement for personnel to time and precisely sequence actions; • Communications key to distributed team working; communications played a part in, and was dependent on, situation awareness; • Co-ordination activities mainly involved communications and creation and maintenance of situation awareness; • Aspects of verbal communication introduce possible sources of error and can be cumbersome;	• Communications links are key element; communications links should be appropriate, explicit and open at all times; • Ensure that roles and responsibilities are well defined and understood by all; each team member should be aware of their own and other team member's roles; • Use procedures to dictate continuous information flow between distributed team members. • Communications media should be considered to remove error potential associated with verbal communications.
Domain: Land warfare **Scenario(s):** Land warfare planning training scenarios **Summary:** EAST approach used to analyse land warfare training scenarios **Reference:** Walker et al (2005)	• Distributed team working comprised three modes of operation; briefing or providing direction, reviewing and semi-autonomous working; • Military command and control relies heavily on tasks that require interaction between distributed team members; • Collaborative tasks primarily involve communication of information and development and maintenance of situation awareness; • Distributed team working highly reliant on verbal communications; great potential for technology to enhance the process.	• System design should consider the different modes of distributed team working; certain technology may be appropriate for one configuration, but inappropriate for another; • Communications links are key element; communications links should be appropriate, explicit and open at all times; • Ensure that roles and responsibilities are well defined and understood by all; each team member should be aware of their own and other team member's roles.
Domain: Military aviation **Scenario(s):** Airborne Warning and Control System (AWACS) scenariois **Summary:** EAST approach used to analyse AWACS scenarios **Reference:** Stewart et al (2008)	• Distributed team situation awareness comprises activated information elements; these activations change over the course of a mission; • Distributed team working systems have a network of linked information elements; the system owns this information network and the individual team members each have different views of the network; • It is important for team members to have awareness of who holds what view and to interpret the usefulness of information that can be passed around in light of these different views; • Network links more critical than nodes themselves in maintaining distributed situation awareness; effective teamwork is dependent upon information transfer across network links	• Communications links are key element; communications links should be appropriate, explicit and open at all times; • Team members need to know which communications links to use and when; • Ensure that roles and responsibilities are well defined and understood by all; each team member should be aware of their own and other team member's roles; • Team members need to be cognisant of what other team members should know during task performance.

4.3 Summary

The review of previous HFI DTC studies on distributed teamwork generates a series of initial guidelines for supporting or enhancing distributed teamwork performance. By summarising the main findings of each of the studies it is possible to generate the following principles or guidelines:

- Communications links are critical to distributed team performance. The communications links present should be appropriate, explicit (i.e. understood by all team members) and be supported by appropriate technological means;

- The roles and responsibilities within distributed teams need to be clearly defined and understood by all team members; each team member should know exactly what it is they are required to do and also what it is that other team members should be doing at all times;

- Procedures are important since they can be used to dictate information flow and situational updates;

- Any systems, tools or artefacts (e.g. mission support systems) used to support distributed teamwork should cater for the different roles, responsibilities and subsequent distinct informational and tool requirements of different team members;

- Timely and accurate information presentation is critical to distributed team performance;

- Team members need to know which communications links to exploit and when to exploit them during the collaborative task;

- Team members should be fully aware of what it is that other team members know (meta situation awareness) throughout task performance;

- Distributed teams should be trained together in a common contextually relevant environment; and

- The organisation of the social network also has a key part to play in the effectiveness of distributed team performance.

5 Guidelines for Distributed Teamwork

5.1 Introduction

Based on the findings derived from our previous case studies on distributed team working and also the wider literature, it is possible to postulate a series of initial guidelines for distributed team working. The guidelines offered are categorised under the three network headings described in Figure 4-1, namely task (e.g. allocation of functions, task organisation, roles and responsibilities, procedures etc.), social (e.g. organisation of team, communications strategies, communications technology etc.) and knowledge (e.g. information requirements, mission support systems etc.). The guidelines offered, whilst not exhaustive, represent an initial attempt at formulating some guidance for distributed team working. It is hoped that further additions to these guidelines are made on the basis of further study in the area.

5.2 Task network guidelines

The characteristics of the tasks being performed by distributed teams can either facilitate or inhibit team performance (Paris, Salas & Canon-Bowers, 2000). The task network involved is a function of the procedures adopted, the team processes used, the roles and responsibilities of the different team members involved and the allocation of function and the level of automation used. The following guidelines relating to the tasks undertaken by distributed teams are offered.

1. *Design distributed team tasks to facilitate co-ordination*. Tasks should be designed to facilitate co-ordination between team members. Task design variables include the level of automation used, workload, time pressure, governmental and organisational regulations, and policies and procedures etc. (Paris et al, 2000).

2. *Ensure roles and responsibilities are clearly defined*. The different roles and responsibilities within distributed teams need to be clearly defined; each team member needs to fully understand what it is that they need to do and also be cognisant of what it is the other team members do. Whilst this is important in terms of overall role and contribution to the team, it is also important on a minute-by-minute basis and each team member should be aware of what the other team members are doing (and thus what they should know) at different points in the task. This should include knowledge of what other team members are doing (tasks) but also knowledge of what other team members should know at that point in time (meta situation awareness). Ambiguity in role definition can adversely impact performance since it leads to confusion over who knows what and who possesses what information.

3. *Use well defined, appropriate communication strategies*. The communication strategies adopted by distributed teams impact the likelihood of successful task performance (Caldwell & Everhart, 1998), and efficient communication strategies enable teams to perform at high workloads in complex systems (Beith, 1987). Based on the importance of communication as an enabler for distributed team working, it is

recommended that teams should have appropriate and clearly defined communication strategies that are designed to enable the effective management of communications-related information. Stone & Posey (2008), for example, suggest that each member's awareness of the current situation could be significantly reduced if communication is not appropriate among members.

One approach typically adopted by distributed teams is closed loop communication (Salas et al, 2001), which involves the initiation of communication by a sender, acknowledgement of receipt of the information by the receiver and then a follow up by the sender to check that the message was interpreted as intended (Salas et al, 2001). The use of such strategies within distributed teams is critical to ensure that communications are completed accurately. Wilson et al (2007) suggest that the use of closed loop communication techniques is critical to ensure that information is clearly and concisely transmitted, received, and correctly understood. In the military domain, for example, Wilson et al (2007) report that a variety of friendly fire incidents have occurred due to inadequately executed closed loop communications.

4. *Use loosely coupled tasks*. A drawback of distributed team working is that tightly coupled work (where the tasks individuals perform are highly dependent on the work of others) is difficult to accomplish as there is an increased requirement for rapid and frequent interaction between workers (Olson & Olson, 2004). If this requirement is not met, it can result in either delays or mistakes being made. Thus where possible for distributed work, loose coupling between tasks is preferable.

5. *Ensure appropriate allocation of function and tasks.* Allocation of function is used in order to allocate jobs, tasks, functions and responsibility to the man or machine for the system in question (Marsden & Kirby, 2004). System, team and procedure designers need to allocate functions appropriately across the distributed team and the technology that the team uses; this should include careful consideration of the capabilities of the different team members and the technology involved.

6. *Optimise team member workload*. The level of workload experienced by operators is a key element in the safety, reliability and efficiency of complex sociotechnical systems (Gregoriades & Sutcliffe, 2007), and inappropriate levels (both too high and too low) have a range of adverse consequences, including fatigue, errors, monotony, mental saturation, reduced vigilance and stress (Spath, Braun & Hagenmeyer, 2006). Teams rely on the appropriate designation of tasks and roles so that they share the level of workload effectively (Sebok, 2000). Inappropriate levels of workload imposed on even one team member can impact the performance of the team as a whole (Roby and Lanzetta, 1957a, b; Dyer, 1984; cited in Paris et al, 2000). Optimising team member workload involves maximising the match between task demands and human capacity (Young & Stanton, 2002).

7. *Use automation sparingly and only where necessary*. According to Paris et al (2000) team tasks are at significant risk when automated technologies are introduced. Despite its many reported benefits (e.g. reduced levels of operator physical and mental workload) many have identified effects of automation that adversely impact operator performance and system safety (e.g. Bainbridge, 1987; Lee, 2006; Young & Stanton, 2002 etc.). These include manual and cognitive skill degradation, operator underload, out-of-the loop

performance decrements (Endsley & Kiris, 1995) and increased levels of workload due to system monitoring requirements. Lee (2006), for example, identifies the following automation pitfalls:

- Out-of-loop unfamiliarity;
- Clumsy automation;
- Automation-induced errors;
- Inappropriate trust (misuse, disuses and complacency);
- Behavioural adaptation;
- Inadequate training and skill loss;
- Job satisfaction and health; and
- Eutectic behaviour.

It is therefore apparent that, despite the impetus for most automated systems being a requirement to reduce operator workload, automation can potentially cause both decreases and increases in workload levels (Young & Stanton, 2002). It has been postulated, for example, that automation can lead to overload through a lack of feedback, increased vigilance demands (Hancock & Verwey, 1997) and increased decision options in certain situations (Hilburn, 1997). Various studies have also identified poorer performance in automated control conditions (e.g. Stanton et al, 1997).

The general consensus is currently that great caution should be taken when using automation in an attempt to enhance performance efficiency and safety in complex systems. Lee (2006) articulates a series of strategies for designing effective automation that includes effective allocation of functions, the use of dynamic function allocation (adaptive and dynamic automation), matching automation to human performance characteristics, representation aiding and multimodal feedback, matching automation to user mental models and the use of formal automation analysis techniques.

8. *Build regular situational updates into procedures*. Regular situational updates facilitate the distributed situation awareness of the team; it is therefore recommended that regular, concise situational updates are built into distributed team procedures. This feature of distributed teamwork has been encountered consistently throughout our case studies; for example, in the land warfare domain situational reports, briefs and back briefs are regularly used to update distributed elements of the team regarding the current status of operations; also, within energy distribution the network control operator is bound by procedure to regularly contact agents working at remote substations to either give them situational updates or to request a current situational update.

9. *Ensure that team members engage in performance monitoring and back-up behaviour*. One of the major components in effective team performance is the ability to provide mutual performance monitoring and back-up behaviour (Salas et al, 2001; Wilson et al, 2007). Mutual performance monitoring represents the “the ability to keep track of fellow team members’ work, while carrying out their own work, to ensure that everything is running as expected and to ensure that they are following procedures correctly” (Wilson et al, 2007); this requires team members to have an understanding of the individual team members, overall team tasks, as well as an awareness of the team members’ roles and responsibilities and an expectation of what team members should be doing. Mutual

performance monitoring and the subsequent feedback provided is important, as it is essential that individual team members or the team as a whole are aware of the number and types of errors being made, in order to prevent errors from occurring; it leads to back-up behaviour and feedback and thus is able to rectify any errors and promote more efficient teamwork. (Salas et al, 2005)

Back-up behaviour is defined by Salas et al (2005) as "the discretionary provision of resources and task-related effort to another . . . [when] there is recognition by potential backup providers that there is a workload distribution problem in their team." When team members recognise, through mutual performance monitoring, that an individual's workload is excessive, then the team can redistribute workload around to other members of the team. Such back-up behaviours prevent overload and ensure that all team tasks are completed, preventing any subsequent degradation of performance. Research suggests that back-up behaviour in teams improves adaptability and performance, and minimises error (Salas et al, 2005; Wilson et al, 2007).

5.3 Social network guidelines

The social network of the distributed team reflects the organisation of the team and the links between team members in terms of communications. The following guidelines related to the social networks of distributed teams are offered.

1. Select the right team members. Obvious but nonetheless often ignored, one of the first things to be done in order to ensure successful team performance is to select the appropriate team members (Paris, Salas & Cannon-Bowers, 2000). Appropriate team member selection involves a careful consideration of individual traits (knowledge, skills and attitudes (KSAs)), team size and composition and team stability (Paris et al, 2000). According to Paris et al (2000), if individual characteristics associated with superior abilities for team co-ordination and performance can be identified then steps to select the appropriate people can be made.

2. *Provide appropriate and clear communications links between team members*. Communication is defined as "the process by which information is clearly and accurately exchanged between two or more team members in the prescribed manner and with proper terminology; the ability to clarify or acknowledge receipt of information" (Cannon-Bowers, Tannenbaum, Salas & Volpe, 1995, p. 345). Clear and efficient communications links have been identified by many as key to distributed team working performance (e.g. Gorman et al, 2006; Stanton et al, 2006; Walker et al, 2006; Salmon et al, 2008). Throughout our research the importance of efficient, appropriate communications links as an enabler for distributed team working has been highlighted. It is critical that collaborative systems possess the appropriate communications links and that the users working with the system understand which communications channels are and are not open to them. This follows on from Stanton et al's (2006) conclusion that the links between agents in a network are more crucial than the agents themselves in maintaining distributed situation awareness.

3. *Use clear, concise communication with immediate feedback*. Again relating to the importance of communication between distributed team members, it is recommended that

any communications made should be clear, concise and have immediate feedback. Salas et al (2001) suggest that clear concise communication is a critical component for the team to remain adaptive and able to accurately assess the situation.

4. *Ensure that the team has appropriate and effective leadership*. The importance of team leadership is exacerbated when team members are distributed across different locations; further the distribution of team members brings with it unique challenges for team leaders (Bell & Kozlowski, 2002). Team leadership is defined as "the ability to direct and co-ordinate the activities of other members, assess team performance, assign tasks, motivate team members, plan and organise actions, and establish a positive atmosphere" (Cannon-Bowers et al, 1995, p. 345). The main role of distributed team leaders is to develop and shape team processes and to monitor and manage ongoing performance (Bell & Kozlowski, 2002). According to Salas et al (2001), leaders are the natural role of influence and gather, assimilate, interpret and communicate key information to the team; leaders use their influence to shape team member knowledge and action. Salas et al (2001) and Bell & Kozlowski (2002) recommend that in distributed teams leaders should:

- Offer clear engaging direction;
- Make specific individual goals explicitly clear;
- Provide an enabling performance situation;
- Closely monitor environmental changes;
- Motivate team members;
- Facilitate cohesion; and
- Provide coaching and process assistance.

5. *Promote the establishment of common ground between team members*. The concept of common ground describes that which is required for workers to communicate meaning efficiently and accurately. This can range from elements in the worker's background (e.g., common background knowledge, practice and technical language) to aspects of high common ground established within a single conversation. In general the more cues that collaborative technology makes available the better common ground can be established, particularly in groups that may begin with relatively little in common; video may, for example, allow pointing and gestural communication; voice as compared with text allows some possibility of awareness of the speaker's mental state and use of rhetoric, humour and so on through tone of voice.

6. *Ensure appropriate information flow is maintained at all times*. Information flow is typically reduced in distributed team environments (Salas et al, 2001). Reduced information flow leads to reduced communications and delays in distributed situation awareness. Within teams information flows both synchronously or asynchronously (Fiore et al, 2003). Caldwell & Everhart (1998) suggest that increases in synchronous information flow lead to enhanced distributed team performance.

7. *Train distributed teams together in a contextually relevant and common environment*. Team training is defined as "a set of tools and methods that form an instructional strategy in combination with requisite competencies and training objectives" (Salas & Cannon-

Bowers, 1997; cited in Salas & Cannon-Bowers, 2000); according to Salas (2004) the primary goal of team training is to develop competencies to allow effective synchronisation, co-ordination, and communication between team members (Salas, 2005). It is apparent that when training distributed teams, the training provided should include the entire team and should be undertaken within the context in which the team is required to perform; Paris, Salas & Cannon-Bowers (2000) outline the concept of team-whole training in which teams are trained within the context of the team and its co-ordination and communications requirements. Salmon, Stanton et al (2007) also suggested that for navy task groups it is more appropriate to train the entire team including all sub-units in a task and environmentally relevant context.

8. *Use appropriate communications media*. There are many forms of technology that can be used to mediate distributed team working; Cuevas et al (2006) suggest that the utility of each approach is ultimately dependent upon the task, the situational constraints and also the team's composition. Further, Stanton et al (2002) suggest that the type of communications media required is dependent upon the task being performed. Therefore building a communications system that supports distributed team working requires a careful consideration of the tasks being undertaken, the processes involved and the conditions in which the collaboration is likely to take place. Thus various aspects of the different communications required throughout a distributed team's work need to be considered when selecting the appropriate communications media to support it; these include the task being performed, the purpose and content of the communication (i.e. what information is being communicated and why), the conditions in which the communication is likely to take place, whether or not the information is communicated synchronously or asynchronously and the degree of interaction between the team members involved. Bolstad & Endsley (2003) present a useful communications technology taxonomy, which details the extent to which various collaborative technologies support different communications (e.g. verbal, face-to-face etc.), different characteristics of collaboration (e.g. time, predictability, interaction etc.), the transmission of different information (e.g. verbal, textual, spatial, video etc.) and different teamwork processes (e.g. planning, brainstorming, shared situation awareness etc.).

9. *Ensure optimum levels of trust between team members and between team members and the technology that they use.* Trust, both between team members and on behalf of the team members in the technology that they use, is critical to efficient distributed team performance. Trust between team members of a distributed team is ostensibly harder to establish due to the impoverished interactions between them (i.e. lack of visual cues, technology based communications). Trust between team members and the technology that they use is also important within distributed teams; for example, Endsley & Jones (1997) point out that "the amount of confidence a crew member has in the accuracy and completeness of the information received and their higher level assessment of that information is a critical element of situation awareness" (Endsley & Jones, 1997, p. 28).

Salas et al (2001) suggest that trust between distributed team members can be promoted by incorporating visual cues into communications and by enhancing cohesiveness and sharing of a common goal between team members; trust between team members and the technology that they use can be enhanced by testing out the system before implementation, developing team member mental models of system functioning and

expected actions and by never completely removing the human decision maker from the loop (Salas et al, 2001).

10. Ensure the development of appropriate attitudes within the team. Much has been made regarding the importance of team attitudes to effective team performance; factors such as team cohesion, mutual trust, collective efficacy and collective orientation have all been found to have a critical role in a team's performance (e.g. Fiore et al, 2003; Salas et al, 2001; Wilson et al, 2007). Fiore et al (2003) report that empirical studies have found that attitude development is attenuated in distributed teams; amongst other things distributed teams have been shown to exhibit lower levels of team cohesion and mutual trust. It is therefore recommended that measures are taken to enhance the collective attitudes of the team in question; this can be achieved through training and increased pre-process interaction (Fiore et al, 2003).

5.4 Knowledge network guidelines

The knowledge required for task performance is directly related to the team's level of distributed situation awareness (DSA) during task performance; DSA has been defined as, "activated knowledge for a specific task, at a specific time within a system" (Stanton et al, 2006). When teams are distributed, DSA is obviously a critical commodity (Salmon et al, 2008); without accurate and up-to-date DSA the team will invariably fail to achieve effective task performance (Stanton et al, 2006). Facilitating the generation and maintenance of appropriate levels of DSA is all about ensuring that the right information can be communicated to the right team members at the right time (Gorman et al, 2006; Stanton et al, 2006); this involves providing appropriate and explicit communications links, ensuring that the appropriate team members are given access to the right information at the right time, and ensuring that team members are cognisant of what other team members are doing and what knowledge they should have. The following guidelines relating to the knowledge networks of distributed teams are offered.

1. Clearly define the information requirements of different team members. Any technology that is used to augment distributed team working needs to be designed on the basis of an in-depth understanding of the information requirements of each of the distributed team members involved. Although ostensibly obvious, unfortunately it is not always adhered to. Matthews, Strater & Endsley (2004) point out that knowing what the SA requirements are for a given domain provides engineers and technology developers with a basis to develop optimal system designs to maximise human performance, rather than overloading workers and degrading their performance; they suggest that the identification of situation awareness requirements is a fundamental step in designing technological systems that optimise work performance.

2. Support distributed (compatible) situation awareness requirements. Any technology used to augment distributed team working should cater for the different but compatible information (situation awareness) requirements of different team members. Within collaborative systems users more often than not have distinct situation awareness requirements, and so the system should be designed so that users are not presented with information, tools and functionality that they do not explicitly require. The system should therefore be designed to support the roles, goals and situation awareness requirements of

each of the different users involved in the process. This might involve the provision of different displays, tools and functions for the different roles and tasks involved.

For example, Bolstad, Riley, Jones & Endsley (2002) analysed the SA requirements of a US Army Brigade and also found explicit differences between the SA requirements of the different officers. In conclusion they suggested that, in military planning systems, team members do not need to know everything that the other team members know; this meant that a single display would not meet the needs of all of the brigade officers. Subsequently Bolstad et al (2002) recommended that displays should be tailored to each officer's needs whilst also providing information relating to the SA of the other officers in the team. Gorman, Cooke & Winner (2006) also suggested that, due to the specialised roles apparent within typical command and control environments, the design principle of giving every team member displays which present all of the information required by the entire team is invalid. Gorman et al (2006) propose that it may in fact be prohibitive and counteractive to give everyone mutual access to the same information.

3. *Support situation awareness transactions between team members.* DSA is developed via SA transactions between team members and artefacts during collaborative tasks. Transactions in SA between team members involve the exchange of SA-related information elements and the subsequent integration of this information with schema. Systems and interfaces that present information to team members should therefore be designed so that they support SA transactions where possible. This involves presenting incoming SA transaction information in conjunction with other relevant information (i.e. information that the incoming information is related to and is to be combined with) and providing users with clear and efficient communications links with other team members. Similarly, procedures can be used to support SA transactions; this might involve incorporating certain pieces of information into procedural communications between team members in order to support SA transactions.

This means that designers need to know exactly what it is that different users need to know and what they need to know it for. To support SA transactions systems should present incoming information in conjunction with the information that it is likely to be used with. For example, a land warfare mission support system could present new incoming information regarding a destroyed combat vehicle to combat service support staff (whose job it is to remove and deal with casualties, repair damage and replenish forces) in conjunction with information relating to routes to and from the vehicle, casualty evacuation routes, distances and projected times, combat effectiveness, medical support information (e.g. nearest hospitals etc.), force replenishment requirements and also resource availability. In this way, the system is supporting the integration of the information from the SA transaction with the combat service support staff's existing awareness and future awareness needs. The same system could present the information regarding the destroyed combat vehicle very differently in light of different user needs. For example, when presenting the information to the Chief of Staff (who is 'running' the battle at the ops table), associated information presented could include the proximal units and their capabilities, the Commander's effects schematic, the task organisation chart and the combat service support staff's assessment. This information would then support the Chief of Staff in allocating the destroyed unit's tasks to another unit on the battlefield.

4. *Promote the development of shared mental models between team members.* Various researchers in the teamwork field have articulated the importance of shared mental models between team members for effective team performance (e.g. Fox, Code & Langfield Smith, 2000; Paris, Salas & Cannon-Bowers, 2000). Mental models refer to the cognitive representations that we use to describe, explain and predict events and to guide our interactions with others (Paris, Salas & Cannon-Bowers, 2000). Rouse and Morris (1986, p. 360) define mental models as "mechanisms whereby humans generate descriptions of system purpose and form, explanations of system functioning and observed system states, and predictions of future system states." Shared mental models are defined as "the activation in working memory of team and task-related knowledge while engaged in team interaction". According to Cannon-Bowers et al (1993; cited in Salas et al, 1995) shared mental models are organised bodies of knowledge that are shared across members of a team (Cannon-Bowers et al, 1993; cited in Salas et al, 1995). Cannon-Bowers and Salas (1997) suggest that shared mental models contain overall task and team goals and knowledge of individual tasks and team member roles.

Shared mental models are critical to a number of key team behaviours, including co-ordination, communication and shared situation awareness. Fiore et al (2003), for example, suggest that effective teams develop shared mental models that they use to co-ordinate behaviour. It is also thought that shared mental models facilitate communications between team members (Perla et al, 2000) and can allow team members to forecast the behaviour of other team members (Fiore et al, 2003; Salas, Stout and Cannon-Bowers, 1994). Paris, Salas & Cannon-Bowers (2000) suggest that shared mental models allow team members to more effectively co-ordinate their behaviours, including allowing them to become better at recognising responsibilities and information needs of team-mates, monitor their activities, diagnose deficiencies, and provide support, guidance, and information as needed. Cannon-Bowers et al (1993; cited in Salas et al, 1995) suggest that when communications channels are limited, shared mental models allow team members to anticipate other team member behaviours and information requirements. Further they suggest that shared mental models of team tasks allow team members to perform functions from a common frame of reference. Stout, Cannon-Bowers, Salas & Milanovich (1999) suggest that mental models "are thought to provide team members with a common understanding of who is responsible for what task and what the information requirements are. In turn, this allows them to anticipate one another's needs so that they can work in sync".

It is clear from the literature then that shared mental models are key to effective distributed team performance. It is therefore recommended that measures are taken to develop shared mental models between distributed team members. This can be achieved through joint team training exercises (Endsley & Jones, 1997; Nofi, 2000). Endsley & Jones (1997), for example, suggest that shared mental models can be developed by direct exposure between teams, formal instruction and joint training exercises.

5. Ensure team members are cognisant of what other team members know and should know during task performance. Our previous case studies highlighted the importance of team members having an understanding of what it is that other team members are doing and therefore should 'know' at different times during task performance; this allows team members to understand when and where information is required in the distributed team. It is therefore recommended that, through team training and system design interventions,

each team member has an appreciation of what it is that the other team members need to know at which points during task performance. Stanton et al (2006), for example, point out that "it is important for the agents within a system to have awareness of who is likely to hold specific views and, consequently, to interpret the potential usefulness of information that can be passed through the network in terms of these views" (p. 1308). Further, Stanton et al (2006) point out that there are two aspects of situation awareness at any given node in a distributed team; individual situation awareness of one's own task and 'meta' situation awareness of the entire system's DSA.

6. Use multiple interlinked systems for multiple roles and goals. When a team is divided into distinct roles and team members have very different goals and informational requirements it may be pertinent to offer separate (but linked) support systems. In the same way that Microsoft Office provides separate word processing (e.g. Word), drawing (e.g. Visio) and spreadsheet (e.g. Excel) tools, distributed team working support systems should provide a suite of mission support tools catering for the different users and roles involved; each tool should have the functionality and information required for the role it is designed to support whilst also containing the ability to see global information.

7. Distribute/present information in a timely manner. The distribution of team members adds a critical temporal dimension to teamwork performance; the timely distribution of information around the team becomes critical to effective performance. It is therefore paramount that information should be distributed and presented to team members in a timely manner at all times; this should be facilitated where possible through the use of appropriate technologies such as global positioning satellite informed positional displays.

8. Distribute/present only accurate information. It goes without saying that the information distributed around, and presented to, distributed team members should be accurate at all times; however, the presence of inaccurate information is a huge problem in distributed team working environments, particularly within military domains. Bolia et al (2007), for example, point out that inaccurate data can emerge from erroneous assumptions made by data fusion algorithms (e.g. a data fusion algorithm deciding that two sensor inputs represent a single entity when they in fact represent two different enemy vehicles), from deliberately fabricated data being fed into the network or from data that is temporally no longer correct (Bolia et al, 2007). Inaccurate information leads to poor or inadequate situation awareness, which in turn is likely to lead to inadequate distributed team performance. Team members need to ensure that the information communicated is accurate at all times and that the information communicated is correctly understood at all times; in addition to this system designers need to ensure that the information presented by any supporting system is accurate at all times.

6 Conclusions

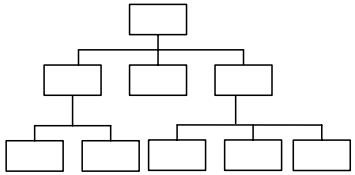
6.1 Summary

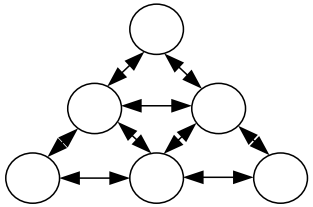
The purpose of this research was to propose a series of initial guidelines for enhancing distributed teamwork. For this purpose a review of the literature and of the HFI DTC's previous investigations into distributed teamwork was undertaken.

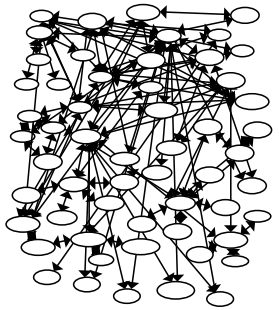
From the literature review, it was concluded that, although distributed teams offer some significant advantages over and above conventional teams, there are various problems associated with their use and that, despite this, little is known about what measures should be taken in order to enhance distributed team performance. Studies focusing on distributed teamwork have, however, identified various characteristics of distributed teams that can be used to inform the development of guidelines. For example, communications and information flow have been found to be reduced and degraded and a lack of team member presence has been found. Further, distributed team performance has been shown to be highly dependent upon the type of task being performed.

The review of the HFI DTC's previous studies on distributed teamwork highlighted a number of characteristics that are generally associated with effective distributed team performance. These include clear, well known communications links, clearly defined roles and responsibilities, the use of procedures to dictate appropriate information flow, the use of systems and tools that cater for different team member goals, roles and information needs, timely and accurate information presentation, meta SA and appropriate organisation of the social network. Further, the review suggested that distributed teams should be trained together in a common, contextually relevant environment.

The findings from the two reviews presented were combined in order to specify a series of initial guidelines for distributed teamwork. The guidelines were categorised around the task, social and knowledge network model underpinning our previous research in the area. A summary of the guidelines is presented in Figure 6-1.







Task Network Guidelines

1. Design tasks to facilitate co-ordination
2. Ensure roles and responsibilities are clearly defined
3. Use well defined & appropriate communication strategies
4. Use loosely coupled tasks
5. Allocate functions and tasks appropriately
6. Optimise team member workload
7. Use automation sparingly and only where necessary
8. Build regular situational updates into procedures
9. Use performance monitoring and back up behaviour

Social Network Guidelines

1. Select appropriate team members based on KSAs
2. Provide appropriate and clear communications links
3. Use clear, concise communication with immediate feedback
4. Ensure the team has appropriate and effective leadership
5. Promote the establishment of common ground between team members
6. Ensure appropriate information flow is maintained at all times
7. Train distributed teams together in a common & contextually relevant environment
8. Use appropriate communications media for the tasks being undertaken and the environment in which they occur
9. Ensure optimum levels of trust between team members and also between team members and the technology being used
10. Ensure the development and maintenance of appropriate attitudes within the team

Knowledge Network Guidelines

1. Clearly define the information requirements of the different team members involved
2. Support compatible team member information requirements
3. Support situation awareness transactions between team members
4. Promote the development of shared mental models between team members
5. Ensure team members are aware of what other members are doing and should know throughout task performance
6. Use multiple but interlinked systems for multiple goals and roles
7. Distribute and present task relevant information in a timely manner
8. Distributed and present only accurate information

Figure 6-1. Summary of distributed teamwork guidelines.

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