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AFRL-HE-WP-TR-2007-0055

The Effects of Collaborative Technologies on Individual and Team Performance in a Network Centric Warfare (NCW) Environment

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February 2007

Final Report for the period August 2005 to May 2007

Approved for public release;
distribution is unlimited.

Air Force Research Laboratory
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NOTICE AND SIGNATURE PAGE

TECHNICAL REVIEW AND APPROVAL

AFRL-HE-WP-TR-2007-0055

THIS TECHNICAL REPORT HAS BEEN REVIEWED AND IS APPROVED FOR PUBLICATION.

FOR THE DIRECTOR

//signed//
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REPORT DOCUMENTATION PAGE	*Form Approved* **OMB No. 0704-0188**

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
01 Feb 2007	Final	August 2005 – May 2007

4. TITLE AND SUBTITLE	
The Effects of Collaborative Technologies on Individual and Team Performance in a Network Centric Warfare (NCW) Environment	**5a. CONTRACT NUMBER** FA8650-05-C-6650
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER 62202F
6. AUTHOR(S) Joseph W. Guthrie* Michael A. Rosen* Eduardo Salas* W. Todd Nelson** Robert S. Bolia**	**5d. PROJECT NUMBER** 7184
	5e. TASK NUMBER 08
	5f. WORK UNIT NUMBER CF
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Department of Psychology* Institute for Simulation & Training University of Central Florida Orlando FL 32826	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Air Force Materiel Command** Air Force Research Laboratory Human Effectiveness Directorate Warfighter Interface Division Collaborative Interfaces Branch Wright Patterson AFB OH 45433-7022	**10. SPONSOR/MONITOR'S ACRONYM(S)** AFRL/HECP
	11. SPONSORING/MONITORING AGENCY REPORT NUMBER AFRL-HE-WP-TR-2007-0055

12. DISTRIBUTION AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited

13. SUPPLEMENTARY NOTES

AFRL/PA Cleared 6/20/2007 AFRL/WS-07-1462.

14. ABSTRACT

Organizations believe that teams are the answer to many of their problems and are implementing them more readily into their daily business practices. The ubiquitous nature of teams in organizations and the current organizational trend of focusing on a more global marketplace have changed the ways in which teams collaborate. In the public and private business sector, organizations foster global partnerships that require employees from different parts of the world to work together to develop new ideas, solve problems, and make decisions. In order to ensure that these teams continue to perform at a high level and produce desired outcomes, researchers must better understand how teams operate in collaborative environments.

15. SUBJECT TERMS

Helmet tracker, helmet-mounted display, dynamic tracker measurement, static tracker measurement

16. SECURITY CLASSIFICATION OF: Unclassified			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Scott Galster
a. REPORT U	**b. ABSTRACT** U	**c. THIS PAGE** U	SAR	**48**	**19b. TELEPONE NUMBER (*Include area code*)**

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI-Std Z39-18

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TABLE OF CONTENTS

LIST OF FIGURES

A CONCEPTUAL MODEL OF COLLABORATIVE ENVIRONMENTS

The past 40 years has witnessed much change in the areas of organizational theory, structure, and business practice. As noted in the literature, teams are heavily used in industry, government, and the military (e.g., Guzzo and Dickson, 1996; and Tannenbaum and Yukl, 1992). Leading up to this are technological advances, geopolitical stability, and free trade agreements that have increased organizational competition within a global economy. In order to remain adaptive and prosper under these circumstances many organizations are witnessing a flattening of traditional, hierarchical structures in favor of teams (Kozlowski and Bell, 2002; and Zaccaro et al., 2002). It is estimated that at least 50% of all organizations and 80% of organizations with 100 or more employees use teams in some form (Banker et al., 1996). Similarly, 80% of surveyed workers report they are currently members of at least one team and this estimate will continue to increase in step with evolving environmental complexities (Fiore, Salas & Cannon-Bowers, 2001). Ultimately, organizations believe that teams are the answer to many of their problems and are implementing them more readily into their daily business practices.

The ubiquitous nature of teams in organizations and the current organizational trend of focusing on a more global marketplace have changed the ways in which teams collaborate. In the public and private business sector, organizations foster global partnerships that require employees from different parts of the world to work together to develop new ideas, solve problems, and make decisions. In order to ensure that these teams continue to perform at a high level and produce desired outcomes, researchers must better understand how teams operate in collaborative environments, answering questions such as: 1) 2) How do team processes change in collaborative environments?, 3) How do different technologies impact the ways in which teams interact in collaborative environments?

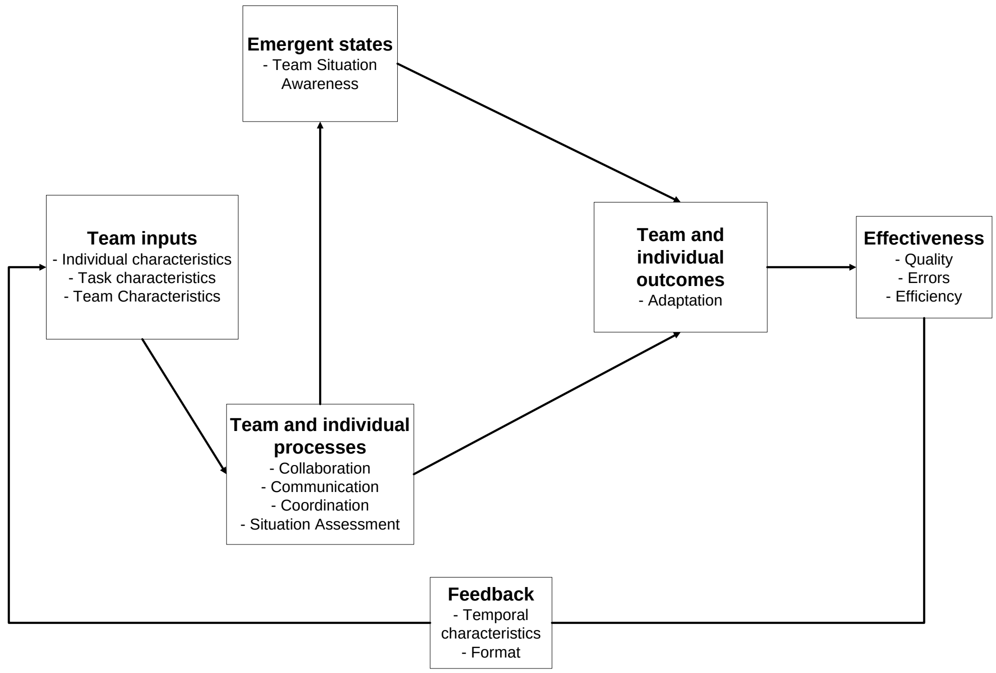
Similar to organizations, over the past two decades there have been vast shifts in the way that military operations are conducted and viewed (e.g., Cebrowski & Garstka, 1998). Given these changes, the U.S. and allied nations have come to consensus that there are extensive benefits to be derived from operating in a distributed, network centric, coalition environment. However, the path toward achieving this reality is paved with a host of issues that need to be overcome prior to the realizations of success. For example, Alberts, Garstka, & Stein (1999) identify three domains of research necessary for NCW to become plausibly effective: (1) the nature of shared awareness and the prerequisites for achieving it, (2) the nature of self-synchronization, and (3) the relationships between these two things. More specifically, individual and team performance will likely be dictated by the ability to develop shared awareness of what has taken place and what strategic/operational objectives need to be accomplished. In order to guarantee continued success in military operations, we must work towards a deeper understanding of the factors that contribute to team success in collaborative environments.

To that end, the moderating effect of technology on this process and individual and team performance is the subject of this paper. The purpose of this paper is threefold. First, we will provide a summary of the literature on teams, distributed teams, and collaborative technology, providing a framework based on prior theory and research. Second, we present a conceptual model, based on existing literature, of how collaborative technology affects individual and team performance. This model will flow from the extensive literature review and framework and provide an integrative view of how collaborative technology impacts individual and team performance outcomes, processes and emergent states. Finally, we use the conceptual model to generate a research plan that focuses on understanding of human performance in a NCW environment. This work represents a novel and significant contribution to the development of effective NCW capabilities as a theory and provides a model of collaborative technologies suitable for use in designing NCW environments. In addition, we hope the model developed in this paper can serve as a cornerstone to future research and development of collaborative environments.

What Do We Know About Teams?

Because teams are so prevalent in organizations and the military, a vast amount of research has been conducted to better understand how teams perform (Guzzo & Dickinson, 1996; Salas & Cannon-Bowers, 2001). From this research, a definition of a team has evolved as two or more individuals working interdependently towards a common goal (Salas, Dickinson, Converse, & Tannenbaum, 1992). In addition, teams often must perform in complex, dynamic, and adaptive environments. From the research on teams, and team performance, several models of team effectiveness have emerged (Campion, Medsker, & Higgs, 1993; Fleishman & Zaccaro, 1992; Hackman & Morris, 1975; Marks, Mathieu, & Zaccaro, 2000; Roby, 1968; Salas, Dickinson, Converse, & Tannenbaum, 1992; Stevens & Campion, 1994). Our framework (see Figure 1) is derived from these models of team performance and supporting literature. Specifically, team effectiveness is a product of the combination of team inputs (i.e. individual characteristics, task characteristics, and team characteristics), team and individual processes (i.e. collaboration, communication, coordination, situation assessment), emergent states (i.e. team situational awareness), and team and individual outcomes (i.e. adaptation). Through feedback received based on previous performance, teams learn, mature, and improve over time.

Figure 1: Framework—Team Performance



What Do We Know About Distributed Teams?

Distributed teams are defined as "team or group whose members are mediated by time, distance, or technology" (Driskell, Radtke, & Salas, 2003, p. 3). In addition, Salas, Burke, and Stagl (2004) describe distributed teams as having distributed expertise and interacting a majority of the time through computer-mediated communication. While most distributed teams do communicate via computer, some teams communicate using technologies as simple as a telephone to more complex technologies such as a virtual office. The use of distributed teams is more prevalent now than at any other time because of the development of new technologies and the emergence of a global marketplace. For example, Bruck (2000) reported that some companies estimate as much as 45% of their workforce is not co-located with management. These numbers indicate a strong need to better understand how distributed teams interact and how decision making effectiveness in distributed teams can be maximized.

Because of the unique performance arrangement of distributed teams, there are, understandably, benefits and disadvantages to using them to complete tasks. The primary advantage to using distributed teams is that one or more of the team members is physically separated from the other team members. This is beneficial to organizations because of savings on travel costs, allowing team members to work from home, and the utilization of the best team members despite their geographical location.

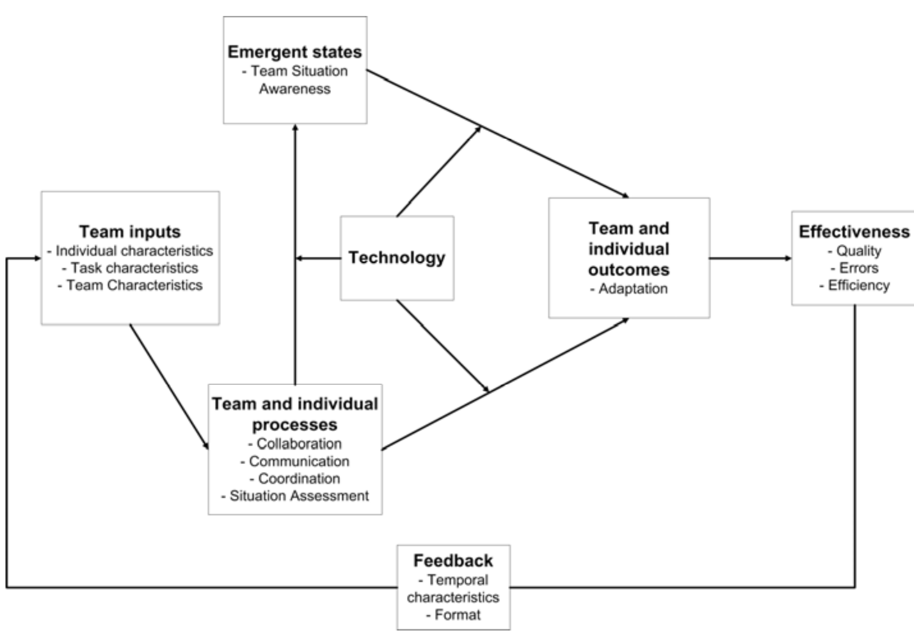
However, because of the dispersion of the team members and the mode of communication being technology, we can assume that the distributed performance arrangement impacts the way team members send, receive, interpret, and encode information. In addition, distribution between team members can affect how they think, act, and feel (Fiore, Salas, Cuevas, Bowers, 2003). Researchers have provided several examples of the effects of distribution on teams. For example, distributed teams have been found to have problems with conflict and shared identity (Mortensen & Hinds, 2001), workload or team opacity (Fiore, Salas, & Cannon-Bowers, 2001), and team leadership (Bell & Kozlowski, 2002). There are several reasons these problems may arise. Distribution influences the cues experts on the team can call upon during naturalistic decision-making, effecting team situational awareness (TSA) and overall performance. In addition, the distributed nature of these arrangements often causes team members to abandon traditional hierarchical structures in favor of self-management practices because team members often have distributed expertise and the "management" of the team is not co-located for a majority of team members. In order to combat these consequences of distributed teams, collaborative technologies have been designed to enable distributed teams to communicate and coordinate more effectively and more like face-to-face teams.

What Do We Know About Collaborative Technology?

Collaborative technologies are designed to allow teams to interact in order to complete a task. While some collaborative technologies have been designed to aid co-located teams (e.g. group decision support systems), most technologies provide distributed team members access to shared information and the opportunity to collaborate. The often cited categorization scheme for collaborative technologies involves a two by two matrix wherein users of the collaborative system can differ in terms of space (collocated or distributed) and time (synchronous or asynchronous) (Olson & Olson, 2003). There are many variations of collaborative tools populating this matrix, such as email, instant messaging, discussion boards, voice or video conferencing, collaboratories, and shared knowledge management tools to name but a few. Different modes of collaborative technology (e.g. chat, instant messaging, shared workspaces, whiteboards, etc.) are capable of bridging physical distance between team members but different modes of collaboration can affect team processes, outcomes and emergent states differently (e.g. Olson & Olson, 2000; Gutwin & Greenberg, 2004; Alge, Wiethoff, & Klein, 2003; Citera, 1998). However, there is currently no integrative model of this relationship; the theoretical and empirical literature is fragmented, insufficient and exists in disparate sources.

One of the main challenges to efforts aimed at developing a generalizable theory of collaborative environments has come in the form of identifying an construct that can be used to classify technologies by the effect they exert on interaction processes. Without such a construct, the development of a theory that can be readily applied to new technologies becomes extremely difficult. This effort began with the work of Short and colleagues (1976) on social presence theory. This early and influential work sought to use a one dimensional scale of social presence to classify a technology. A systems social presence is defined as the degree to which the system provides an 'awareness' of the other person(s) involved in the interaction (cf. the more modern variant of workspace awareness; Gutwin & Greenburg, 2000; 2002; 2004). Technologies with a level of social presence that matched the level of interpersonal involvement in the task were thought to be more effective (cf. with recent work on task technology fit; Zigurs & Buckland, 1998). The social presence theory is related to the more recent line of research started by Daft and Lengel (1986) called media richness theory. Like Short and colleagues, Daft and Lengel sought to characterize technologies with a one dimensional scale. The media richness construct is basically an extension of social presence theory in that media richness functions in a similar manner as social presence, just at a finer level of detail. The latest variant of this effort to advance an underlying abstraction for the effects of a technology's influence on interaction processes is media naturalness (Kock, 2002; 2004; 2005). The media naturalness of a specific technology is defined as the degree to which it supports or suppresses one of five aspects of human face to face interaction: 1) synchronicity, 2) collocation, 3) ability to convey and observe facial expressions, 4) ability to convey and observe body language, and 5) the ability to convey and listen to speech. As technologies become less natural (i.e. more aspects of human face to face interaction are suppressed), three outcomes are observed. First, the task of interaction becomes more cognitively effortful for those engaged in the interaction. Second, the ambiguity of the communication increases. Third, the level of physiological arousal decreases.

Figure 2: Framework—Team Performance in Collaborative Environments



Previous research has shown that technology acts as a moderator in a typical I-P-O model of team performance (Driskell, Radtke, & Salas, 2003). Therefore, by adding technology to the framework of team performance in Figure 1, we have created a framework for team performance collaborative environments (see Figure 2). Determining the specific nature of the relationship between technology and team inputs, processes, and outcomes has proven difficult. The majority of the research conducted into the performance effects of collaborative technology has compared performance of teams interacting face-to-face (collocated teams) to teams interacting through collaborative technology (virtual teams); in general findings have shown that in relation to collocated teams, virtual teams have lower levels of effectiveness, take longer to complete tasks, and poorer member satisfaction (Baltes, Dickson, Sherman, Bauer, & LaGanke, 2002). However, there is evidence that the technology mode interacts with task type on performance outcomes (Strauss & McGrath, 1994). In relation to team performance outcomes Hertel, Geister, and Konradt (2005) state in their review of empirical research into virtual teams that there is some conceptual basis for fitting collaboration modes to specific content and team purpose or goals in the literature, but that there is a great need for systematic research to find an optimal fit between team and task characteristics and collaborative technology mode. Our goal then has been to review and integrate the existing literature base, in order to develop a conceptual model of team decision making in distributed collaborative environments. We hope to validate the model empirically, providing theory-based, empirically-tested answers for the types of technology to be utilized for a particular team type, performing a particular task.

A Conceptual Model of Collaborative Environments

In order to fully represent the factors involved in collaborative team performance, we utilized the framework developed in Figure 2 and, based on existing theoretical and empirical literature determined which inputs, processes, emergent states and outcomes would likely comprise team performance in collaborative environments based solely on a bottom-up approach. Figure 3 represents a testable, multilevel model of team performance in collective environments. The model takes into account the role of various input variables on individual and team processes and emergent states and how those drive individual and team outcomes and team effectiveness. Central to the model; however, is the impact of technology on these relationships and ultimately team effectiveness. The model presented here is predictive primarily of action teams (see Sundstrom, De Meuse, & Futrell, 1990 for a description) with moderate to high levels of interdependence but should generalize to teams with diminishing levels of interdependence. In teams with lower levels of interdependence, the impact of technology would be decreased due to a reduced need for communication and information sharing.

Team Inputs

Task Characteristics. We consider both task interdependence and communication structure as task characteristics. While workload is considered a task characteristic, we discuss it later because of its direct relationship with the type of technology utilized by the team. Task interdependence is the degree to which team members must rely on one another to perform their tasks effectively given the design of their jobs (Saavedra, Earley, & Van Dyne, 1993). Task interdependence is operationalized along a continuum from the lowest level, pooled, to sequential, followed by reciprocal, and at its most complex team interdependence. Several researchers have discussed the need for greater collaboration between team members as task interdependence increases (Galbraith, 1987; March & Simon, 1958; Perrow, 1970; Thompson, 1967). Varying levels of task interdependence can affect the required level of cooperation between team members, the group's ability to prevent a loss in productivity or efficiency, the nature of interpersonal interactions among team members, and overall team performance.

Communication structure is the degree to which communication among team members is open or restricted. In an open communication structure, each team member can communicate with any other team member (Bolton, Chatterjee, & McGinn, (2003). As communication structure is restricted, team members may only be allowed to communicate with certain other team members. Open communication structures offer greater amounts of shared information across all team members. Typically, this would be more desirable in teams to build shared knowledge. However, in teams where some member's roles are more independent, a restricted communication structure would remove needless information and allow team members to focus solely on their task.

Individual Characteristics. Individual characteristics of team members are critical to the functioning and performance of a team. Researchers have sought for years the right combination of individuals to place on a team. In this research, some of the most often investigated individual characteristics have been personality, cognitive ability, and leadership. In this section, we review these characteristics.

Personality has often been studied as a predictor of team performance. Typically, personality is defined along five core dimensions: openness, conscientiousness, extroversion, agreeableness, and neuroticism. Despite some literature indicating an effect of personality on decision-making (Janis & Mann, 1977), a meta-analysis showed that personality measures are not valid predictors of performance (Martinussen, 1996). More recently researchers have attempted to utilize personality variables in individuals as a method of choosing the best team members. Chidester, Helmreich, Gregorich, and Geis (1991) investigated how pilot personality affected crew coordination and performance. Results of their study indicated a positive relationship between pilots and crew coordination when individuals had high levels of instrumentality, expressivity, mastery, and work and low levels of negative instrumentality and verbal aggressiveness. Driskell and Salas (under review) review the literature associating various components of personality with the likelihood that the individual will be a good team member. Driskell & Salas (2003) found that individuals with low levels of dominance and high levels of affiliation are more likely to be team players and willing to engage in the team processes that are necessary for teams to be effective.

Cognitive ability is a conscious intellectual activity often measured by various tests of mechanical comprehension, spatial orientation, perceptual speed, attention, time sharing, visualization, instrument comprehension, or global intelligence tests (Martinussen, 1996). Cognitive ability influences knowledge acquisition (Colquitt et al. 2000) and self-efficacy and skill acquisition (Hunter, 1986). Cognitive ability is also highly predictive of performance (Martinussen, 1996). Recently, Lepine (2003) found that individuals high in cognitive ability are more likely to be able to adapt to changes in the task. This body of research indicates that individuals high in cognitive ability are more likely to learn and retain the knowledge and skills required to complete tasks and is a highly desired trait when selecting individuals for teams.

Leadership as an individual characteristic is comprised of the attributes that make a good leader. Janis (1989) identified the personality characteristics of openness, conscientiousness, and neuroticism as critical components of individuals in leadership-type roles.

Team Characteristics/Composition. We consider mutual trust, familiarity, and expertise as critical components of team characteristics/composition. Mutual trust is the shared belief that team members will perform their roles and protect the interests of their teammates (Salas, Sims,

& Burke, (2004). In distributed teams where face-to-face interaction is minimal mutual trust becomes more important. Mutual trust among team members promotes communication and information sharing between team members (Jones & George, 1998) and affects team processes and outcomes such as group participation and contribution and product quality (Bandow, 2001). Without mutual trust, teamwork processes critical to performance in the cockpit, such as mutual performance monitoring and backup behavior, may be interpreted as team members keeping tabs on each other, as opposed to looking out for each other.

Familiarity can be defined as a team's history of interaction (Harrison, Mohammed, McGrath, Florey, & Vanderstoep, 2003). Similar to mutual trust, the need for familiarity in distributed teams is heightened due to the physical distance between team members. Research findings indicate that familiarity in teams increases perceptions of effectiveness, implicit coordination, and reduction in workload (Leedom & Simon, 1995).

Expertise is a level of stable, repeatable task performance (Ericcson & Smith, 1991). There is significant work on delineating the psychological and physiological mechanisms that mediate expert performance (see Ericsson, Charness, Feltovich, & Hoffman, 2006). As these mechanisms are significantly different depending on the task constraints of the domain (Ericsson & Charness, 1994), expertise has come to be viewed as a 'prototype' (Sternberg, 1997; Hoffman, Feltovich, & Ford, 1997; Holyoak, 1991). This means that general characteristics of expertise can be identified (e.g., knowledge amount and organization, memory skill, self-monitoring, problem and situation representation), but these abilities contribute to expert performance differentially depending on task demands. Additionally, expertise has come to be conceptualized on the team level as well. An expert team is defined as "a set of interdependent team members, each of whom possesses unique and expert level knowledge, skills and experience related to task performance, and who adapt, coordinate, and cooperate as a team producing sustainable and repeatable team functioning at near optimal levels of performance" (Salas, Rosen, Burke, Goodwin, & Fiore, 2006, p. 440). Expertise on the team level is best identified through performance levels, just as it is on the individual level. This team level expertise involves not only the expertise of the individual in completing his/her task work, but expertise of all team members in teamwork processes (e.g. communication, coordination) necessary for effective performance on the team level.

The relationship between team inputs leads to the following propositions:

Proposition 1: Tasks high in interdependence require teams composed of individuals with more collectively oriented personality characteristics, higher cognitive ability, and possessing more attributes of leaders.

Proposition 2: Tasks with a restricted communication structure require teams composed of individuals with more collectively oriented personality characteristics, higher cognitive ability, and possessing more attributes of leaders.

Proposition 3: As team tasks require higher levels of interdependence the need for higher levels of mutual trust, familiarity, and expertise on the team increases.

Proposition 4: As communication structure within the team is restricted between team members the need for mutual trust, familiarity, and expertise on the team increases.

Proposition 5: Teams composed of individuals with more collectively oriented personality characteristics, higher cognitive ability, and possessing more attributes of leaders will have higher levels of mutual trust, team cohesion, and be more quickly identified as an expert team.

Team Processes

Team processes have been termed the 'black box' of team research because of the difficulty involved in measuring processes. This difficulty is primarily due to the fact that team processes are mostly abstract concepts as opposed to concrete and the fact that team processes are dynamic as opposed to static. For distributed teams interacting through some technological medium, we identified the team processes of leadership and teamwork to be critical components of a team's success.

Team leadership is an ongoing process of influence (Stagl, Salas, & Burke, in press) that involves the direction/coordination of team members, assessment of team performance, allocation of tasks, motivation of subordinates, planning/organizing, and maintaining a positive team environment (Marks, Zaccaro, Mathieu, 2000). Based on this definition of team leadership, it is this process that drives team members to work together. Team leadership has been suggested to become more critical as task complexity increases (Jacobs & Jacques, 1987; Zaccaro, Rittman, Orvis, Marks, & Mathieu, 2002). The importance of leadership is further magnified in distributed teams, not only due to the often increased complexity of the task, but also due to the aforementioned lack of shared cues between the team members. Therefore, it is the team leader(s) responsibility to ensure that all members of the team communicate effectively.

Teamwork can be defined as "a set of interrelated behaviors, actions, cognitions and attitudes that facilitate the required taskwork that must be completed" (Salas, Guthrie, Wilson-Donnelly, Priest, & Burke, 2005, p. 187). For the purposes of our model, we follow the framework for teamwork proposed by Salas, Murphy, and Wilson (under review). Their framework takes a three-pronged approach to teamwork, consisting of communication, coordination, and cooperation. Communication refers to the process of giving and receiving information between team members during the task. Coordination corresponds to the behavioral and cognitive components of teamwork. Cooperation represents the attitudinal processes of teamwork.

The Impact of Team Inputs on Individual & Team Processes

Task Characteristics. Task characteristics have a direct impact on processes. Several researchers have discussed the need for greater collaboration between team members as task interdependence increases (Galbraith, 1987; March & Simon, 1958; Perrow, 1970; Thompson, 1967). In addition, Naylor and Dickinson (1969) discuss how the communication structure of the team can influence how the work is performed.

This literature leads to the following propositions concerning task characteristics and processes:

> *Proposition 6:* When teams have a high level of task interdependence and restricted communication structure, the processes the team engages in must be more efficient in order to produce desired outcomes.

Individual Characteristics. Individual characteristics of team members will differentially affect the processes in which teams engage. When combined correctly, all other factors being equal, the team will have the best chance to succeed. A team of individuals with personality traits that promote a team orientation, high cognitive ability, and attributes of a strong leader would typically be identified as providing a team with the individual mechanisms to work well together.

> *Proposition 7a:* Team members possessing personality characteristics that promote team orientation will exhibit more effective team processes.
>
> *Proposition 7b: Team members possessing high cognitive ability will exhibit more effective team processes when team roles are efficiently integrated.*
>
> *Proposition 7c: Teams comprised of members possessing attributes of a strong leader will exhibit effective team leadership and, in turn, more effective teamwork.*

Team characteristics/Composition. Team characteristics/composition impact the way in which teams perform tasks. Mutual trust between team members has been shown to affect an array of team processes (Bandow, 2001). In addition, mutual trust among team members promotes communication and information sharing between team members (Jones & George, 1998). Similarly, familiarity between team members has a strong influence on processes because of the history of interaction (Harrison et al., 2003). Expert teams result in more effective team leadership and teamwork than teams not reaching a similar level of expertise.

Proposition 8: When teams have high levels of mutual trust, familiarity, expertise, and a strong leader, the processes teams engage in lead to higher levels of team performance.

The Relationships between Processes

Team leadership is the driving force behind the other processes that comprise teamwork and make possible effective team performance (Cannon-Bowers, Tannenbaum, Salas, & Volpe, 1995; Kozlowski, gully, Nason, & Smith, 1999; McIntyre & Salas, 1995). For example, without effective team leadership, information sharing through communication may be incomplete or inaccurate.

Proposition 9: A team with more effective team leadership processes will result in better teamwork as evidenced by higher levels of cooperation and coordination and more effective communication.

Situational Assessment and Team Situational Awareness

A widely adopted definition of individual situation assessment (SA) is the process of building situation awareness, the "reception 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" (Endsley, 1995, p. 36). It is critical to make the distinction between the *process* of situation assessment and its *product*, situation awareness. The situation assessment process is a function of short-term sensory memory, perception, working memory and long-term memory (Endsley, 2006). Extensive reviews of the specific processes involved in building a situation awareness have been produced by many researchers (e.g. Durso & Gronlund, 1999; Endsley, 2000). For the purposes of this paper, we adopt the view that SA is characterized by both bottom up processes of pattern recognition of salient cues in the environment as well as top down processing whereby expectations and goals guide attention and processing. An individual's SA ability is limited by his or her short and long term working memory capacities (Ericsson & Kintsch, 1995; Endsley, 1997) because the individual must actively integrate new perceptions of the environment with his/her current understanding.

The SA process and TSA are important components of team cognition and the relationship between this individual level SA process and the team level emergent state of TSA is best described through a team cognition framework. Therefore, we provide a brief explanation of team cognition to explicate this relationship. Team cognition is generally understood as the interaction of and dependencies between intra-individual and inter-individual level processes (Fiore & Schooler, 2004); that is, team cognition emerges from individual cognitions as the individual team members engage in team interactions and process behaviors. A descriptive analogy can be drawn between the two core components of team cognition (i.e. individual cognition and team processes) and cognitive processes and structures on the individual level (Cooke, Salas, Kiekel, & Bell, 2004). Specifically, within an individual, long term knowledge structures (e.g. mental representations, semantic network) must be acted upon by cognitive processes (e.g. mental simulation, storage, retrieval) in order to make use of the information represented by those structures. In a similar manner, team processes such as communication and coordination are the means by which individual level knowledge structures and dynamic understanding are acted upon to produce team level knowledge. In this way, the multilevel nature of team cognition is apparent; individual level static knowledge structures (e.g. mental models of the task) are leveraged by an individual with information cues experienced in the environment to create a dynamic understanding of the situation, situation awareness. As team members interact, they process this individual level knowledge and dynamic understanding into a team level dynamic understanding of the present environment faced by the team (i.e. team situation awareness; Salas, Stout, & Cannon-Bowers, 1994; Salas, Prince, Baker, & Shrestha, 1995). Additionally, this process yields long-term team knowledge such as shared mental models of the task and team (Orasanu, 1990; 1994; Orasanu & Salas, 1993). The long-term knowledge and dynamic understanding resulting from the team cognition process are held at the individual level, that is, they reside within individual team members, but are considered at the team level because the processing, filtering, and transformation of information through team interactions results in knowledge that is specific to the team, and not solely bounded by the individual. It is through this general team cognition process that the SA process feeds into the development of TSA.

Team situation awareness (TSA) is more than the sum of the individual members' SA and includes team process behaviors as well (Salas, Prince, Baker, & Shrestha, 1995; Stout, Cannon-Bowers, & Salas, 1996). Thus, TSA can be defined as an active construction by team members of "a situation model which is partly shared and partly distributed and, from which they can anticipate important future states" (Artman, 2000, p. 1113). Particular aspects of TSA may be "partially distributed" in the sense that a team member may not possess a particular piece of information about the present situation, but in the event that this knowledge becomes relevant to their performance, team members know which of the other team members does hold this needed information. TSA relies on contextualized strategic knowledge—combinations of declarative and procedural knowledge that create an understanding of the coordination of behaviors within a specific operational situation (Stout et al., 1996; Salas, Cannon-Bowers, Fiore, & Stout, 2001).

Communication is a vital process by which TSA is achieved and maintained. Teams that engage in cross checking of information and confirmation of communication known as closed-loop communication are generally higher in TSA than those that do not (Schwartz, 1990; Bowers, Jentsch, & Salas, 1998). This process ensures that messages that are sent are received and that all team members are operating with the most up to date information. When communicating about problems, teams high in TSA explicitly define the problem, clearly articulate plans and strategies for solving problems, actively seek relevant information about the problem at hand, and explicitly communicate the rationale for selected courses of action (Orasanu, 1990; Orasanu & Salas, 1993). These characteristics of team communication solidify and unify the team's model of the situation and problem. Additionally, teams high in TSA are able to engage in overt strategizing without loosing accuracy in their awareness of the situation (Salas, Stout, & Cannon-Bowers, 1994).

Problem identification and conceptualization are diagnostic to TSA levels since they require the team to hold models of the normal operational context as well as the present context and detect deviations between the two. Teams high in TSA are able to rapidly identify problems or potential problems in the environment and they are able to recognize when action is needed (Prince & Salas, 1989). When teams high in TSA detect abnormalities in the environment and are confronted with conflicting information, they attempt to determine the underlying causes for the abnormality or conflict (Prince & Salas, 1989). TSA is also characterized by team members having common explanations of cues in the environment, compatible assessments of the situation, and common expectations of task and information requirements (Salas, Stout, & Cannon-Bowers, 1994). These attributes indicate that the team posses the requisite knowledge structures and interaction processes to create effective TSA. Based on the above discussion, we advance the following proposition regarding the relationship between SA and TSA.

> *Proposition 10:* There will be a positive relationship between SA and TSA such that more effective SA processes on the individual level will be associated with more accurate and complete TSA.

Workload & Team Workload

The Impact of Workload & Team Workload on Processes

Workload is one of the constructs that we specify at both an individual and team level. At the individual level workload is the relationship between the resources available within a person and the resources required to complete a task (Norman & Dobrow, 1975). Similarly, team workload is the relationship between the performance capacity of a team and the demands placed on a team by the task environment (Bowers, Braun, & Morgan, 1996).

The impact of workload, both individual and team, on team processes is considered to be an inverted U-shape. Specifically, low levels of workload and high levels of workload have a negative impact on team functioning, while moderate levels of workload would have a positive influence on team function. Levels of workload negatively impacting processes interfere with a team's ability to interact interdependently or reduce the level of interoperability between team members resulting in lower levels of coordination (Morgan & Bowers, 1995).

Proposition 11: Team members experiencing exceptionally low or high levels of workload will provide less leadership, resulting in less cooperation and coordination and less effective communication.

The Impact of Workload & Team Workload on SA & TSA

The SA process is a cognitive resource intensive task; the greater the mental workload placed upon an individual in the course of task performance, the less resources that individual will have to devote the process of SA (Wickens, 2001; 2002). Therefore, workload generally has a negative relationship with SA. However, the relationship between workload and SA is complex and can diverge due to aspects of system and task design as well as individual characteristics (Endsley, 1993; 1995). The relationship between team workload and TSA is analogous to the relationship between individual workload and SA. When the team task requires more resources than the team is capable of providing, team coordination and communication may decline and result in lower levels of TSA (Bowers, Braun, & Morgan, 1997). This general issue has been called the 'communication overhead' of team cognition (Macmillan, Entin, & Serfaty, 2004). Specifically, communication is necessary in order to build the shared representation of the situation that is a prerequisite to coordinated team performance. Increased levels of team workload means that the team will have fewer resources available to engage in the communication behaviors necessary for building and maintaining TSA. Given the above, we can advance the following two propositions.

Proposition 12: There will be a negative relationship between individual workload and SA such that increased levels of individual workload will be associated with less effective SA processes on the individual level.

Proposition 13: There will be a negative relationship between team workload and TSA such that increased levels of team workload will be associated with less accurate and complete TSA.

Individual and Team Adaptation

The Relationship between Individual and Team Adaptation

Adaptation is generally described as "adjustment to environmental conditions… modification of an organism or its parts that makes it more fit for existence under the conditions of its environment" (Merriam-Webster online), and "the way living organisms cope with environmental stresses and pressures" (Wikipedia). In the context of task performance, adaptation on the individual level involves the ability to adjust to new and unexpected variations in the task by inventing new procedures or modifying existing procedures to meet the new environmental and task demands (Hatano & Inagnaki, 1986). The appropriate selection of task strategies or decision making heuristics can similarly be viewed as a form of adaptation to dynamic task demands (Payne, Bettman, & Johnson, 1993; Schunn, McGregor, & Saner, 2005). The importance of adaptation in complex and dynamic environments can not be overlooked (Canas, Quesada, Antoli, & Fajardo, 2003; Cellier, Eyrolle, & Marine, 1997; Cara & Lagrange, 1999). We consider individual adaptation to be an outcome, specifically, the effective change in performance processes in response to a change in the individual taskwork demands. In this sense, adaptation is made possible by 1) a deep conceptual understanding of the task and domain characteristics (Barnett & Kozlowski, 2002; Feltovich, Spiro, & Coulson, 1997), and 2) effective self-regulatory processes (Zimmerman, 2006). A deep conceptual understanding of the task domain allows the individual to make sense of unexpected variations of the task and to create and use task strategies that effectively compensate for these variations. Adaptation requires more than the development of procedural skill and automaticity. Additionally, self-regulatory processes allow the individual to monitor his/her present environment, internal cognitive and affective states, as well as behavioral task processes (Bandura, 1986). Without an understanding of the present environment and performance processes, adapting performance to the environment would be impossible (Cohen, Freeman, & Wolf, 1996; Cohen, Freeman, & Thompson, 1998). This highlights the role of situation assessment processes in individual adaptation. Creating better representations of the situation is a fundamental distinction between experts and novices across domains (Ericsson & Lehmann, 1996; Feltovich, Prietula, & Ericsson, 2006) and is a primary mechanism of being responsive to environmental circumstances (Randel, Pugh, & Reed, 1996). The ability of an individual to generate accurate and complete representations of the current situation as well as projections of likely future states of the system will improve the ability of that individual to make effective adaptations. Therefore, we advance the following proposition.

> Proposition 14: There will be a strong positive relationship between situation assessment and individual adaptation such that more effective situation assessment processes will be associated with higher levels of effective adjustment to changing task demands and characteristics.

Adaptation exists on the team level as well. It has been shown that teams are able to alter their performance processes in response to changing environmental conditions. Most notably, the inability for researchers to consistently identify a relationship between increasing time pressure and performance outcomes (cf. Urban, Weaver, Bowers, & Rhodenizer, 1996; Hollenbeck, Sego, Ilgen, Major, Hedlund, & Phillips, 1997) has been explained by the teams ability to adapt its team performance processes to changing environmental conditions.

Specifically, teams have been found to increase the speed of cognitive operations, rely more heavily on implicit communication, and filter certain low priority tasks so as to maintain high levels of performance outcomes in the face of increasing time pressure (Adelman, Miller, Henderson, & Schoelles, 2003). To account for such activity, several models of team performance have been advanced in recent years highlighting the importance of adaptation and evolution at the team level (e.g. Entin & Serfaty, 1999; Burke, Stagl, Salas, Pierce, & Kendall, in press; Morgan, Salas, & Glickman, 2001). We adopt Burke and colleagues (in press) definition of team adaptation. Specifically, team adaptation is "a change in team performance, in response to a salient cue or cue stream, which leads to a functional outcome for the entire team" (Burke, Stagl, Salas, Pierce, & Kendall, in press). For these coordinated changes in performance strategies, the team must share an accurate understanding of the situation. TSA directly impacts the ability of a team to execute a task as well as to adjust to task variations that effect the entire team (Burke, Stagl, Salas, Pierce, & Kendall, in press); that is, TSA is a necessary pre-requisite to team adaptation in that the team must first understand the environment in order to adjust its strategies, coordinate, and distribute work. Therefore, we can advance the following proposition concerning the relationship between TSA and team adaptation.

> Proposition 15: There will be a positive relationship between TSA and team adaptation such that more accurate and complete levels of TSA will yield more effective changes in team performance processes.

Distinctions between individual and team adaptation can best be viewed by adopting the perspective that teams develop two distinct sets of skills: 1) a set of taskwork skills related to individual performance, and 2) a set of teamwork skills such as team interactions, affects, and coordination and communication skills (Morgan et al., 2001). From this perspective, individual adaptation involves changes in the performance processes of taskwork skills and team adaptation involves changes in teamwork skills. For example, and individual team member may encounter changes in the environment that effect his or her individual task. If there are no interdependencies attached to this specific task component (i.e. this particular aspect of the task does not require attention from other team members), then any adaptation in performance processes to compensate for this change will be limited to individual. Conversely, if the environmental change effects aspects of the task environment such that team interdependencies are changed (e.g. a highly interdependent task needs adapted performance processes, or an individual had to individually adapt to such a degree that it effects his/her performance on other more interdependent tasks), then team performance processes must be altered and the adaptation is at the team level. However, team performance processes are emergent and are compiled from individual level processes (Burke et al., in press; Kozlowski & Klein, 2000). For this reason, individual adaptation feeds into team adaptation. Specifically, team members whose individual adaptations are more effective will be better able to meet their individual task demands; their responses will be more effective and timely. This increase in individual performance processes allows more resources to be devoted to teamwork tasks such as coordination and communication. Therefore, we can advance the following proposition.

> Proposition 16: There will be a positive relationship between individual and team adaptation such that more effective individual adaptations will be associated with more effective team adaptations.

Decision Making Effectiveness

The ultimate outcome of interest is the decision making effectiveness of the team, the degree to which the performance processes of a team meet the team goals. There are numerous ways to characterize the effectiveness of a decision with task constraints often dictating the most logical approach to choosing a specific metric and setting a criterion. However, some variants of the efficiency of the decision, quality of the decision, and errors in decision making are highly generalizable factors contributing to the effectiveness of decision making in most domains. Individual adaptation exerts an influence on the overall decision making effectiveness. As the changes of an individual's performance processes in relation to dynamic aspects of the task environment increases become more effective, the individual will be able to make more accurate and timely contributions to the overall team decision making effectiveness. Additionally, an individual well adapted to task constraints will produce fewer errors. This relationship holds for team adaptation and decision making effectiveness as well. The higher levels of effective team adaptation, the adjustment strategies and balancing work within the team, will result in higher levels of decision efficiency, decision quality, and lower error rates. This occurs because the demands of task environments characterized by complex and dynamic changes necessitate rapid diagnosis of the situation and prioritization, selection and execution of strategies and actions (e.g., Orasanu & Connolly, 1993, Kozlowski, 1998, Kozlowski, Toney, Mullins, Weissbein, Brown, & Bell, 2001). Given this, we can advance the following propositions.

Proposition 17: There will be a positive relationship between levels of effective individual adaptation and decision making effectiveness, such that higher levels of adaptation will be associated with higher decision making effectiveness (i.e. lower levels of errors, increased efficiency, and increased quality).

Proposition 18: There will be a positive relationship between team adaptation and decision making effectiveness, such that higher levels of team adaptation will be associated with higher decision making effectiveness (i.e. lower levels of errors, increased efficiency, and increased quality).

Feedback

The Impact of Feedback on Task Characteristics & Team Characteristics/Composition

Feedback from the environment is a critical aspect of team performance. Both aspects of feedback structure and timing influence the effectiveness of individual and team performance (Brehmer, 1990). Feedback structure can tale the form of either cognitive, feedforward, or outcome. Feedback with a cognitive structure focuses on providing information about the relationships between the environment and the decision makers perception of the environment (Beroggi & Wallace, 1997). Feedforward feedback involves providing a model of the task before the task begins. Outcome feedback is simply knowledge of the results of actions. This is considered the least effective form of feedback as it does not provided the decision maker with enough information to diagnosis what aspects of performance are and are not effective. Feedback with a cognitive structure has been shown to be most effective as it helps decision makers to develop an accurate representation of how the task and performance strategies are interacting (Sengupta & Abdel-Hamid, 1993; Beroggi & Wallace, 1997); however, some studies show that a feedforward structure is superior (Gonzalez, 2005). The effects of feedback structure on team characteristics and composition and task characteristics has not been adequately researched; however, the role of diagnostic feedback (i.e., feedback about process—cognitive or feedforward structure) in increasing levels of expertise is well documented (e.g. Ericsson, Krampe, & Tesch-Romer, 1993). Similar relationships are hypothesized for the other team characteristics and compositions.

Proposition 19(a): The use of feedback structure supporting performance diagnosis (i.e., cognitive and feedforward feedback structures) will be associated with higher levels of team characteristics and composition (i.e. mutual trust, familiarity, expertise, and leader) than outcome feedback alone.

In addition to the structure of feedback, the temporal characteristics of feedback exert an influence on performance. Delays are an inherent part of complex systems. The outcomes of an action are distributed across time in that they are rarely accessible immediately after the action has been completed. This issue is often exacerbated with the increase in technological mediation of performance, that is, as the components of the system are distributed physically. In general, increasing amounts of feedback delays are associated with poorer performance in dynamic decision making tasks. This is often attributed to an inability in human operators to infer causality in nonlinear dynamic environments as well as poor representations of the temporal characteristics of a system (Diehl & Sterman, 1995; Brehmer, 1996). Because of this, it is proposed that there will be a negative relationship between feedback delay and team characteristics and composition such that longer delays will produce negative outcomes in the development of expertise, trust, and leader.

Proposition 19(b): There will be a negative relationship between feedback delays and team characteristics and compositions such that longer delays in feedback will be associated with lower levels of expertise, trust, and leader over time.

Effects of Technology

We adopt the media naturalness construct (Kock, 2002; 2004; 2005) discussed earlier to summarize the effects of various aspects of technology on performance processes. Specifically, varying features of collaborative technologies selectively support or suppress specific aspects of interaction that are present in human face to face communication, such as: Synchronicity, collocation, ability to convey and observe facial expressions, ability to convey and observe body language, and the ability to convey and listen to speech. The media naturalness of a specific communication system is defined as the degree to which it supports or suppresses the above aspects of interaction, with the media becoming less natural as it suppresses more features of interaction. The team performance processes of distributed and virtual teams are mediated by various technological systems. The naturalness of such systems exerts influence on the processes of team performance. Based on the concept of media naturalness and the model of team performance detailed above, we can synthesize a model of team performance in collaborative environments. Generally, decreasing degrees of naturalness in these technological systems has the following effects: 1) increasing the cognitive effort involved in task performance, 2) increasing levels of ambiguity in communication, and 3) decreasing levels of affect in communication. Specific effects of varying the degrees of media naturalness on workload and team performance processes are discussed below.

Workload & Team Workload

Although typically levels of workload are determined by the task being performed, the utilization of technology in distributed teams will affect the level of workload an individual and a team experiences. As the technology utilized by teams to communicate becomes less natural the effect on workload and team workload is greater.

> *Proposition 20a:* Technology utilized by teams that is less natural will increase the levels of workload and team workload above and beyond the workload associated with the task alone.

Proposition 20b: Over time, as teams utilize the same technology to interact, the technology will approach the naturalness of face-to-face communication negating its previous negative impact.

Team Leadership and Teamwork

The technology utilized to aid in team interaction will impact the processes in which teams engage. Because team processes are negatively impacted by distributed team members, the technology used by teams should be chosen to reduce the negative influence. Thus, technology that is more natural should be utilized. If less natural technology is used as a primary means of interaction, sufficient time should be provided to the team to practice so that the negative effects of the less natural technology diminish.

Proposition 21: Teams using more natural computer mediated communication technologies in order to interact will have less of a degradation of the team leadership and teamwork than teams using less natural computer mediated communication types.

SA and TSA

The naturalness of the media used to mediate team interactions will exert an influence on the relationship between SA and TSA. Technology moderates the relationship between SA and TSA, such that various characteristics of technology affect the strength of the relationship between SA and TSA. The process of building TSA from SA involves team processes such as communication and coordination (Endsley, 1995; Salas, Prince, Baker, & Shrestha, 1995). Additionally, explicit strategizing has been identified as a step in building a dynamic shared understanding of the present task situation from existing mental models (Salas, Stout, & Cannon-Bowers, 1994; Stout, Cannon-Bowers, & Salas, 1996; 1999). The levels of media richness of a technology will influence the effectiveness of these team processes and behaviors necessary for constructing TSA from SA. The increased cognitive effort of task performance generated by lower levels of media naturalness will decrease the amount of resources available for team members to engage in the 'communication overhead' involved in generating and maintaining TSA. Additionally, the increased ambiguity in communication found in the use of less natural media will decrease the relationship between SA and TSA. Therefore, we advance the following proposition.

Proposition 22: There will be a positive moderating effect of media naturalness on the relationship between SA and TSA such that higher levels of media naturalness will strengthen the positive relationship between SA and TSA.

Individual and team Adaptation

Additionally, technology will impact the relationship between individual and team adaptation. Specifically, less natural communication media will introduce ambiguities in communication and cognitive workload that will retard the processes of adapting team performance processes, but, to the degree that individual taskwork does not rely on communication with other team members, will not affect individual adaptation. Adaptation on the team level requires adaptive team members as well as effective TSA and communication processes. Individual adaptation feeds into team adaptation, but the effects of technological mediation on individual adaptation are lessened in that individual taskwork performance processes do not necessarily rely on team communication. This is not the case for team adaptation. Therefore, we advance the following proposition.

Proposition 23: There will be a positive moderating effect of media naturalness on the relationship between individual and team adaptation such that higher levels of media naturalness will increase the positive relationship between individual and team adaptation.

Conclusion

Teams are an integral part of organizations and the military. When properly trained and utilized, teams are able to work more efficiently and with greater success than individuals working alone. Due to the plethora of research investigating teams, we have learned much, and as a result, organizations and the military have been successful in their implementation of traditional, face-to-face teams. With the current and ongoing changes in organizational structure and military operations, the means by which teams interact is changing and; therefore, our theories of teams and team performance needs to be refined. No longer is team performance and effectiveness a product of face-to-face interactions, but rather a product of technology mediated interactions. As a result, we have presented here a conceptual model of teams in collaborative environments. It is hoped the model will serve both theoretical and empirical importance. First, the model is of theoretical importance because it attempts to tie together and extend a fractured literature base. While there is a tremendous amount of literature on teams and a growing trend to research and develop new collaborative technologies, there has been little attempt at taking an interdisciplinary approach to develop a true theory of collaborative team performance. This model attempts to bring together widely accepted theories of team performance and utilize the media naturalness theory explain how distributed teams will perform and change over time.

From an empirical perspective, this model provides a point of departure for research investigating distributed team performance in collaborative environments. In addition, we hope it will spur future research and fill in current gaps in the research literature with regards to the effect of different technologies on the levels of workload individuals and teams experience while completing tasks, and the relationship between technology and individual and team process variables and emergent states including team leadership, teamwork, situation assessment, team situational awareness, adaptation, and team adaptation and the subsequent impact on team effectiveness.

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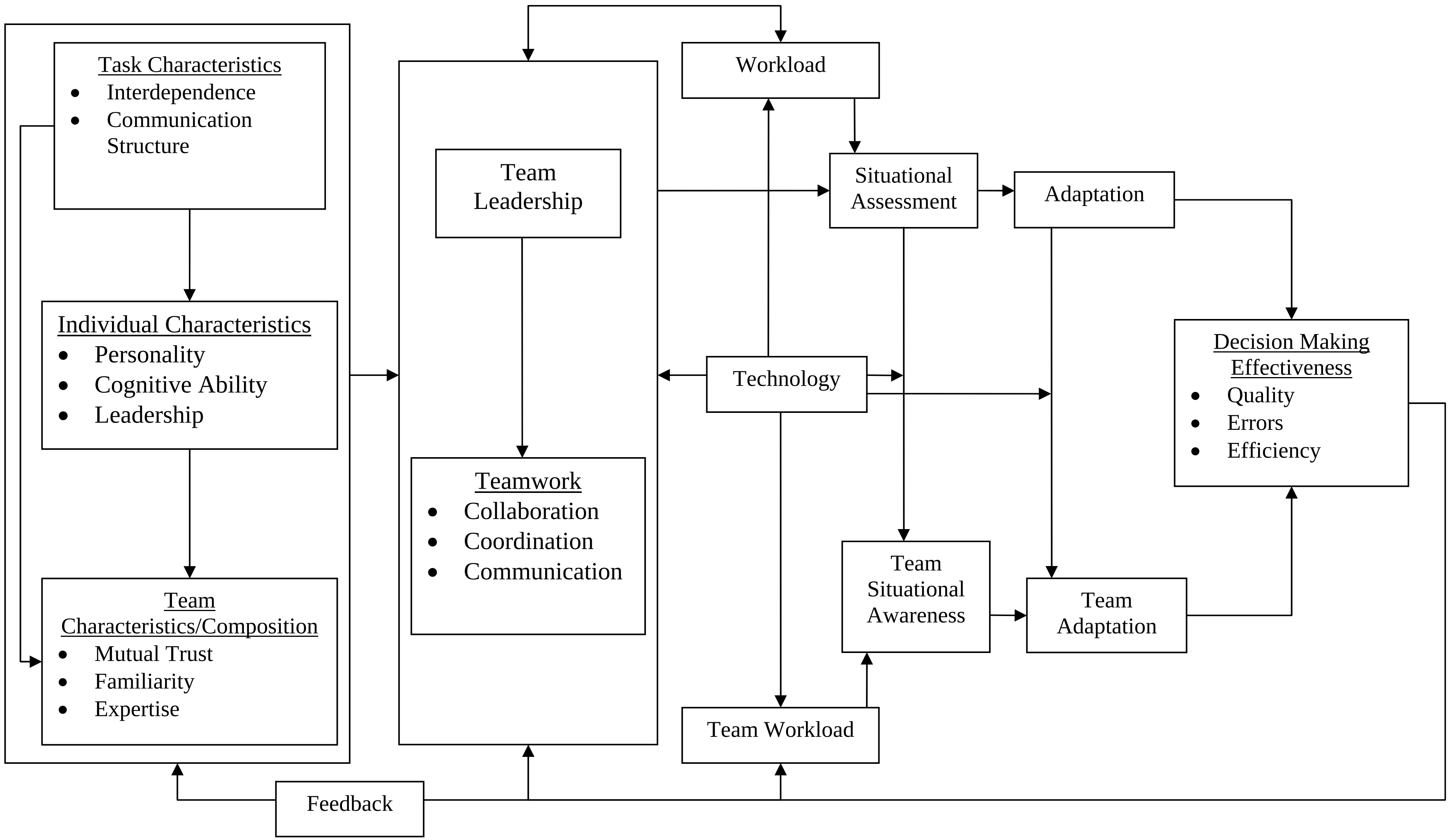
Task Characteristics
Interdependence
Communication Structure
Individual Characteristics
Personality
Cognitive Ability
Leadership
Team Characteristics/Composition
Mutual Trust
Familiarity
Expertise
Team Leadership
Teamwork
Collaboration
Coordination
Communication
Workload
Situational Assessment
Adaptation
Technology
Decision Making Effectiveness
Quality
Errors
Efficiency
Team Situational Awareness
Team Adaptation
Team Workload
Feedback