Team Decision Making in Complex, Time-Sensitive Environments

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Abstract

The goal of the FY04 Air Force Mission Oriented Investigation and Experimentation (MOIE), "Improving Time-Sensitive Team Decision Making," was to study teams of operators in realistic time-sensitive venues. We sought to understand the kinds of tasks and functions people perform in these collaborative environments, why the tasks are so challenging, how they are currently done, and how to better support team performance. This paper describes a framework, developed as part of this research effort, to guide observation and analysis of team performance data.

In complex military domains such as Time Sensitive Targeting, human performance, the effectiveness of supporting systems, and the decision-making environment are strongly interdependent. To develop robust insights and findings for these domains, we advocate an overarching *system perspective*, where "the system" of interest encompasses the team of operators, the full set of information technologies and tools they use, and the decision-making environment that affects them. A primary purpose of the proposed "Interdependent Team, Systems, and Environment" (ITSE) Framework is to make explicit that team decision making and other collaborative behavior cannot be characterized in isolation, but rather occur with the support (or hindrance) of tools and as influenced by important tasks, goals, and constraints in the decision-making environment. The same supporting technologies may be used differently by different teams, on different collaborative tasks, and in different contexts.

This paper describes the framework, depicted as three overlapping circles representing the broad components of Team, Systems, and Environment. A box pointing to the intersection of those components depicts data recommended for comprehensive analysis. The paper describes each component, followed by discussion of complexities created from interactions and interdependencies among them and the implications for team performance.

Lastly, the paper describes the complementary types of data (direct observation, chat logs, and interviews) that were used by the MOIE research team to analyze collaboration in time-sensitive environments. A matrix summarizes desired characteristics of these data and the relative strengths and weaknesses of each; a combination of these three types of data can address the desired characteristics and capture many of the Team, Systems and Environment interdependencies put forth in the ITSE framework.

KEYWORDS: Team(s)

Collaboration

Decision making

Time-sensitive

Framework

Section 1

Introduction and Overview

Human collaboration and decision making have become critically important processes in dynamic military domains characterized by complex interactions among people, systems, and environments. A recent study of Time Sensitive Targeting (TST) processes in Operation Enduring Freedom (OEF) concluded that

> "complex decision-making processes consume a far greater proportion of the TST timeline than do communications between sensors, shooters, and other TST process components. The TST process is being slowed down, not by the speed of information movement, but by the human factors involved in decision making when complex issues are involved." (LaVella 2003, p.22).

The goal of the FY04 Air Force Mission Oriented Investigation and Experimentation (MOIE), entitled Improving Time-Sensitive Team Decision Making, was to study teams of operators in realistic time-sensitive venues to understand what kinds of tasks people do in these collaborative environments, why those tasks are so challenging, how they are currently done, and ways to better support team performance. This paper describes a framework, developed as part of this research effort, intended to guide our observation and analysis of team performance data.

It can be tempting for engineers to focus heavily on the specific systems and technologies that individual operators use, hoping to find ways to improve a given tool and thereby improve human performance. Other research perspectives focus strongly on the social aspects of teamwork, documenting how issues such as trust, interpersonal communication, and team culture can influence the effectiveness of team processes. But in military domains such as Time Sensitive Targeting, both the particular technologies used and the individuals involved in collaborative decision making are constantly changing. *It is not productive to separately examine a team's process, or the usefulness of a technology; the important issue is how a team actually makes use of available technologies in support of their goals.* Moreover, the decision-making environment can offer widely varying challenges from one engagement to the next due to different rules of engagement, different scenarios and types of targets, different leadership styles, and so on. The OEF study of TST concluded that

> "TST process execution is situationally dependent and shaped by influences external to the kill chain. While the fundamental TST critical path process should be considered the common starting point or baseline of any theater contingency TST process, allowances must be made for the unique requirements of each conflict. Each TST process regimen will be defined by the nature of the war and operational objectives. Campaign specific external influences, such as NCA *[National Command*

> *Authority]* guidance on the political/humanitarian concerns in OEF and their effects on ROE *[Rules of Engagement]*, shape kill chain execution." (LaVella 2003, p.24).

The environmental goals and constraints will strongly influence the team process, and how the team interacts with technology. Ultimately, it is at the intersection of these three components – the team, their systems, and the environment -- where team decision making and overall performance are embedded; the three components are strongly interdependent.

To develop robust insights and findings for these complex domains, we need a framework that reinforces a *system perspective,* where "*the system*" (singular) of interest encompasses the team of operators, the complete set of technologies and tools they use, and the decision-making environment that affects them. Before proposing such a framework, I define the three components in the following section.

Section 2

Team Component

The Team component focuses on human-centric issues. For example, appropriate and sufficient *coordination* is critical for effective team decision making. Individuals must not only understand the overall team purpose and function well enough to know what information to share with whom in a given situation, but must keep abreast of the status of coordinated tasks, of the actions of other key team members, and of potentially changing priorities. Coordination can be particularly difficult for large or geographically distributed teams, as well as for heterogeneous teams (such as coalition forces) that may have distinct subgoals.

The team of operators who must collaborate to reach conclusions and make decisions will also be heavily influenced by their team *culture* and *affect*. This includes their familiarity with one another and with team processes, attention paid to issues such as rank and status, and the level of cohesion and amount of trust between members of the team. Competing cultures can make it difficult to form a cohesive team; the more team membership crosses different military services, nationalities, or other organizational boundaries, the more complexity is introduced into the team process.

Individual and team *cognition* relate to the thought processes and mental tasks operators perform, and play a key role in team performance. Team members with appropriate skills and domain experience have the potential for high performance, but may still experience cognitive overload because of too much information, conflicting information, conflicting or unclear goals, constant distractions, or multiple channels of input. Individual overload and coordination difficulties can contribute to problems with cognition at the *team* level, such as a loss of shared situational awareness, confusion over team priorities, or inadvertent misdirection of others' attention. It is vital to recognize the existence and impact of these social issues, as well as the fact that they are remarkably hard to deal with.

> "It isn't that these issues aren't interesting," Robert Wilensky, a professor of computer science of the University of California, Berkeley, put it succinctly, "it's just that these problems, like so many social/psychological issues, are *so* hard that one had to hope that they weren't on the critical path." (Brown and Duguid 2000, p.40).

Issues of human cognition and collaboration are now squarely on the critical path of our sponsors. They must be explicitly folded into our attempts to design and improve technological solutions. See Figure 1.

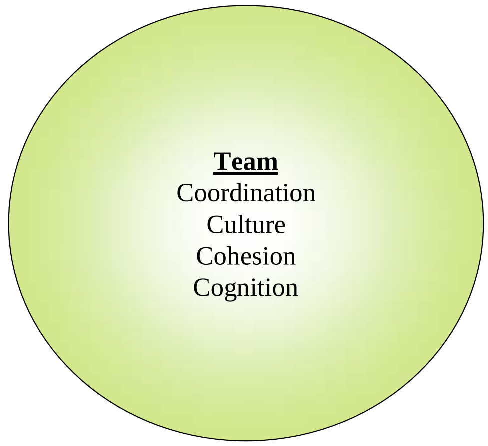

Figure 1. Team Component

Section 3

Systems Component

The Systems component refers to the *set* of systems (plural) and technologies -- broadly defined – used to support collaborative decision making in time-sensitive domains. (In contrast, the term "system" (singular) will be used to refer to the complex combination of human cognition, information technologies, and surrounding environment.) The Systems component focuses on the technologies used, the information they provide, and the way it is provided (e.g., via text, visual display, audio, etc.). This broad definition of systems includes not only tailored software applications designed to help automate a particular operator's task, but more general technologies such as email, phones, text chat, or audio chat. Systems need not even be electronic; a physical display of aircraft positions on a tabletop map, a chart on a white board, paper notes or diagrams passed among team members, or face to face conversations would all fall under this definition since they represent a means of providing information. In addition, the quality and appropriateness of the resulting information, which encompasses its accuracy, pedigree, and the degree of ambiguity surrounding the information, is an important characteristic of the Systems component. See Figure 2.

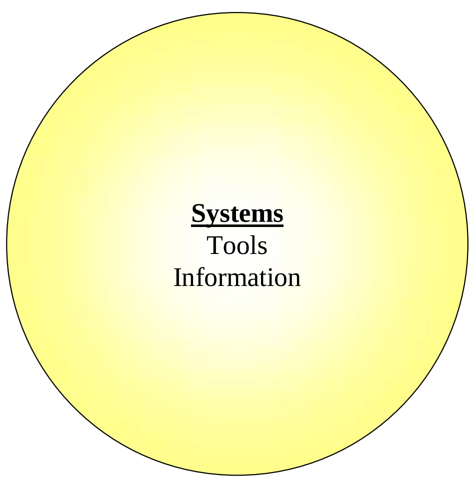

Figure 2. Systems Component

Section 4

Environment Component

The Environment component refers to those external elements surrounding the human operators and technological systems that may direct, constrain, or otherwise influence performance. They encompass the organizational goals to be met and tasks to be accomplished, the rules of engagement, the degree of time pressure, and the types of decision-making scenarios operators face. Physical realities such as layout, temperature, noise, or weather are part of the environment. Also included are organizational factors such as the organizational culture, staffing levels, work schedules, incentive structures, and the political and legal climate. These aspects of the work environment can exert a powerful influence on team behavior, and will not be detected by observing operators in a restricted laboratory environment. Moffat (2003) stresses that environmental interactions are indispensable to understanding the behavior of a complex system:

> "The lesson to be learned from this is that complex systems cannot be studied independently of their surroundings. Understanding the behavior of a complex system necessitates a simultaneous understanding of the environment of the system." (Moffat 2003, p.xxi.)

An important part of the ITSE methodology is therefore the observation of teams in as close a facsimile of their real operating environment as is possible, such as exercises, experiments, or training events that incorporate realistic scenarios and time sensitivity. See Figure 3.

Figure 3. Environment Component

Section 5

Interdependent Teams, Systems, and Environment (ITSE) Framework

The primary purpose of the proposed "Interdependent Team, Systems, and Environment" (ITSE) Framework is to guide data collection and subsequent analysis of team decision making. The framework provides a perspective emphasizing that the team of operators, set of technologies used, and operational environment together comprise the *overall system* of interest. I depict the components of Team, Systems, and Environment as overlapping spheres in a Venn diagram to highlight their interdependencies (Figure 4). Real time team decision-making behaviors are embedded at the dynamic intersection of those three components, and it is there research focus and observations must be directed. As the decision-making team, their supporting systems and the environment interact, behaviors and phenomena emerge that could not necessarily be predicted. Teams adapt their collaborative and decision-making processes, and the way they use available technologies, to real-time challenges in their environment.

The ITSE Framework draws from existing theories of *structuration* (Orlikowski, 2000; DeSanctis and Poole 1994; Poole and DeSanctis 1990). For example, the interplay between the *environment* and the way systems are used resonates with DeSanctis and Poole's discussion of *context*: their appropriation analysis "tries to document exactly how technology structures are being invoked for use in a specific context" (DeSanctis and Poole 1994, p.133). The interdependencies highlighted in the ITSE Framework relate even more closely to Orlikowski's concepts of *situated* practices and relevant circumstances: "structures of technology use (technologies-in-practice) are not fixed or given, but constituted and reconstituted through the everyday, situated practices of particular users using particular technologies in particular circumstances. By attending to such ongoing (re)constitution, a practice lens entails the examination of emergence, improvisation, and change over time as people reconfigure their technologies or alter their habits of use" (Orlikowski 2000, p.425).

To further illustrate some specific interdependencies relevant to team decision making, I will discuss the areas of the diagram representing overlap between pairs of components in the framework: systems with environment, teams with systems, and teams with environment. Although these pairwise discussions are admittedly simplifications since all *three* components are always in play, they are useful for highlighting key interactions.

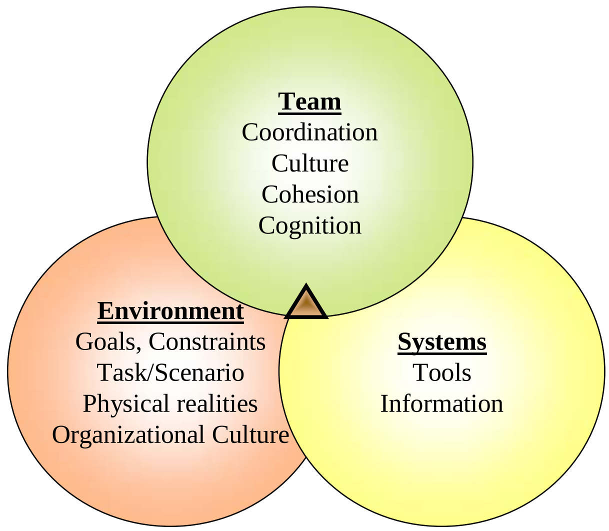

Figure 4. ITSE Framework

Section 6

Systems with Environment

The type and use of systems must accommodate realities in the surrounding environment. For instance, redundant systems may be needed if power or communication linkages are intermittent. Some advanced technologies may not be appropriate in particularly hot, dusty, wet or windy settings, forcing a reliance on lower technology solutions. The way information is displayed or shared may need to be altered to be clearly visible and/or audible, and the location of displays must be suited to the team's physical layout and patterns of use. At a subtler level, the degree of compatibility between information technology capabilities and organizational culture will influence how readily those capabilities are adopted. For example, a feature enabling wide knowledge sharing and reuse is unlikely to be adopted in an organizational climate characterized by individual incentives, competition, and knowledge hoarding (Orlikowski 2000).

For effective decision making, systems should also *reflect* key characteristics of the operational environment back to the team, thereby helping to provide situational awareness. Ideally, systems will support human decision making by monitoring the environment for key changes (such as the movement of a target or enemy troops) and generating the relevant cues and information for human evaluation. *This systems-environment interaction, in which information regarding a potentially significant event in the environment is generated, is typically what sets a round of human collaboration and decision making in motion.* Moreover, as the decision-making environment becomes increasingly complex, the *third* component – human cognitive and sensemaking capabilities – plays a key role in guiding the systems-environment interaction. Decision makers may recognize emergent patterns or unanticipated events, and can then redirect systems to monitor for different types of information in the environment. See Figure 5.

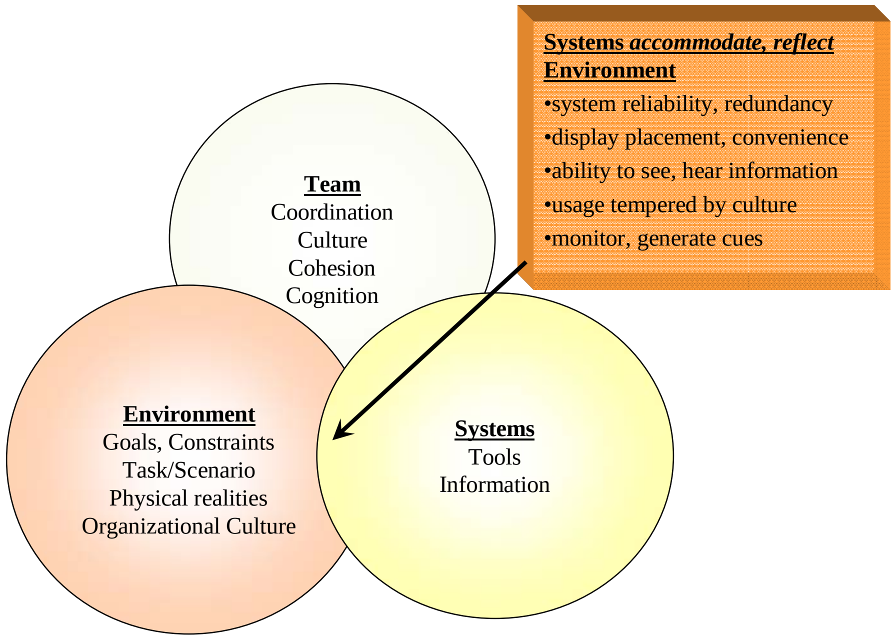

Figure 5. Systems with Environment

Section 7

Team with Environment

Moffat (2003) emphasizes that the behavior of a complex system cannot be studied independently of its surroundings. Team behavior and dynamics respond to and interact with pressures from the environment. Environmental factors such as time pressure, high stakes, challenging scenarios, temperature, ambient noise, and work schedules can affect operator stress and fatigue, potentially impairing cognition. The layout of operator stations will determine who can easily communicate with whom, thereby influencing team coordination and cohesion. Less obvious environmental factors, such as whether operational goals, priorities, and constraints are clearly articulated, can also strongly influence the team's shared frame of reference and level of coordination. Organizational priorities implicitly communicated via decisions on staffing levels, investment in operator training, and incentive structures will influence the team's motivation and attitude toward risk. As teams cross boundaries of military service, organization, or nationality, the impacts on team culture and behavior become increasingly complex and difficult to predict. Sometimes the interaction between human operators and such a complex environment is a forcing function for the *third* component, supporting technologies, to evolve. Systems may need to be augmented or changed in order to better support team cognition and decision-making. See Figure 6.

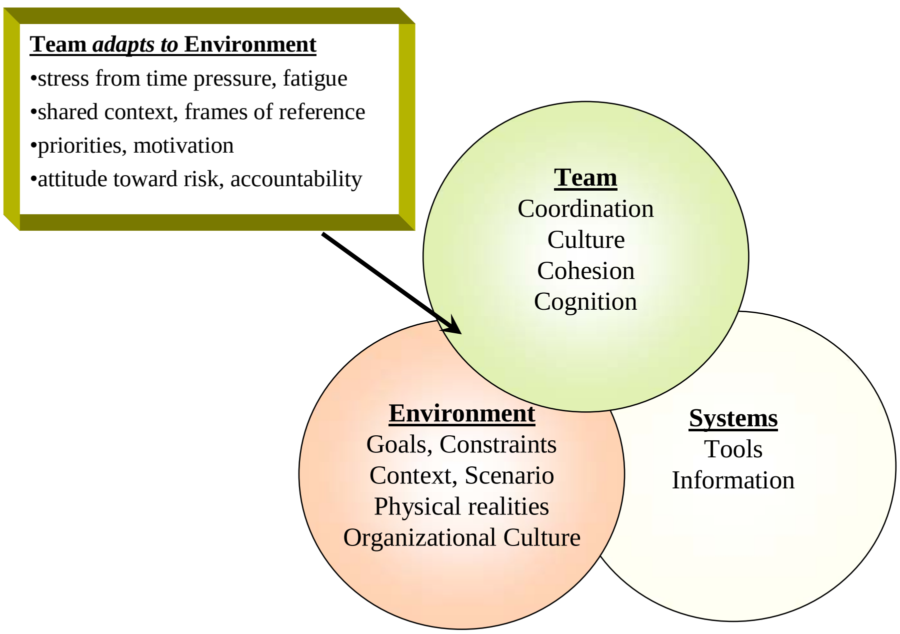

Figure 6. Team with Environment

Section 8

Team with Systems

Given MITRE's System Engineering role, I pay particular attention in this Section to the interdependencies between systems and people (in this instance, *teams* of operators collaboratively making decisions). In computer-supported human decision making, a key goal is to achieve an effective balance between the roles for humans and the roles for systems. As Brown and Duguid note, "Some futurists seem continuously anxious to replace humans with "bots" in certain tasks without quite appreciating how people accomplish those tasks. In general, it will be better to pursue not substitution but complementarity." (Brown and Duguid, p.62.) The ITSE methodology considers how the human-systems composite behaves, which informs choices about allocating tasks between humans and technology.

Although systems are typically designed with specific uses and purposes in mind, teams will *appropriate* those tools in whatever way best suits their goals and needs. *People are "purposive, knowledgeable, adaptive, and inventive agents who engage with technology in a multiplicity of ways to accomplish various and dynamic ends. When the technology does not help them achieve those ends, they abandon it, or work around it, or change it, or think about changing their ends"* (Orlikowski 2000, p.423). In a related vein, Adaptive Structuration Theory (DeSanctis & Poole, 1994; Poole & DeSanctis, 1989) states that information technology is not an object passively received or equivalently adopted by all groups, but rather is appropriated--or actively adapted and restructured--by each group uniquely. Operators may refuse to use an application for its intended purpose, or completely, if they find it cumbersome or ill-suited to their tasks; they will devise creative workarounds using simpler or more intuitive means. Operator use of a given technology also depends on the trust in the technology and in the information it produces. As a result, teams may frustrate or surprise developers by adopting a robust tool with limited or general-purpose functionality over a more advanced or tailored tool that is less reliable. Some teams will be more effective than others at systematically appropriating technologies to effectively accomplish tasks and achieve their goals of high performance (Boiney, 1998).

The type of technology or modality chosen to communicate information can strongly influence team dynamics. Tradeoffs must constantly be made on the fly. For example, team members can typically gain trust more readily and have greater influence over others when communicating face-to-face than with chat or email, but face-to-face is time-consuming and does not scale to large or distributed teams. Similarly, it may be easier to immediately capture and direct the attention of others with audio announcements than with a text messages because operators are already bombarded with visual inputs. But audio transmissions are usually not stored and may be missed by intended recipients who are temporarily elsewhere. A physical, tangible display such as a tabletop map may be the clearest way to share spatial and geographic information, but it is limited to a fixed location and must be manually kept current. The communication modalities that team members choose for particular tasks can mean the difference between clear, efficient information sharing and information overload. Technologies also differ in the degree to which they support or hinder awareness of other team members' activities, which can have a significant impact on coordination. Many issues with team-systems interactions can be influenced by operator training that looks beyond "buttonology." In addition, the systems themselves are not static. Technologies need to evolve to better support the human team and its interactions with the environment. See Figure 7.

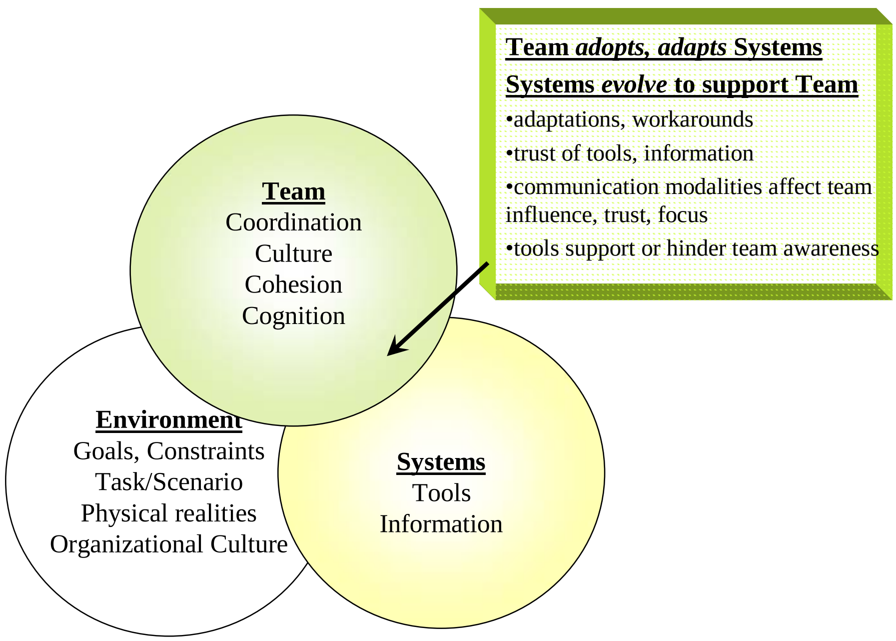

Figure 7. Team with Systems

Section 9

Targeted Data Collection

When collecting data on team decision making, the challenge is to reflect all three components of the ITSE framework: issues relating to the team of human operators and their means of coordinating and reaching decisions, characteristics of the systems being used in support of collaboration and decision making, and characteristics of the environment likely to influence the application of technologies and the performance of the team. *To adequately reflect the Team-Systems-Environment space, we use a coordinated blend of three approaches: direct observation of operators, analysis of chat logs, and expert interviews.* See Figure 8.

In direct observation, we serve as observers and are co-present with operators in their normal work environment. This is consistent with ethnographic observation (Nardi and O'Day, 1999) and contextual inquiry techniques (Holtzblatt and Jones, 1993). We are able to overhear conversations, see tool placement and usage, observe when operators get up to speak to others, and detect more subtle body language suggesting frustration, confusion, fatigue, or other mental and emotional states. In conducting chat analysis, we capture and comb through text logs of messages sent between team subgroups or "rooms" within chat tools. When conducting interviews, we focus on operators with extensive experience in the field and solicit their perspective on the amount and quality of information provided, difficulties or success stories involving information sharing and coordination, and social issues such as team familiarity, cohesiveness, and trust.

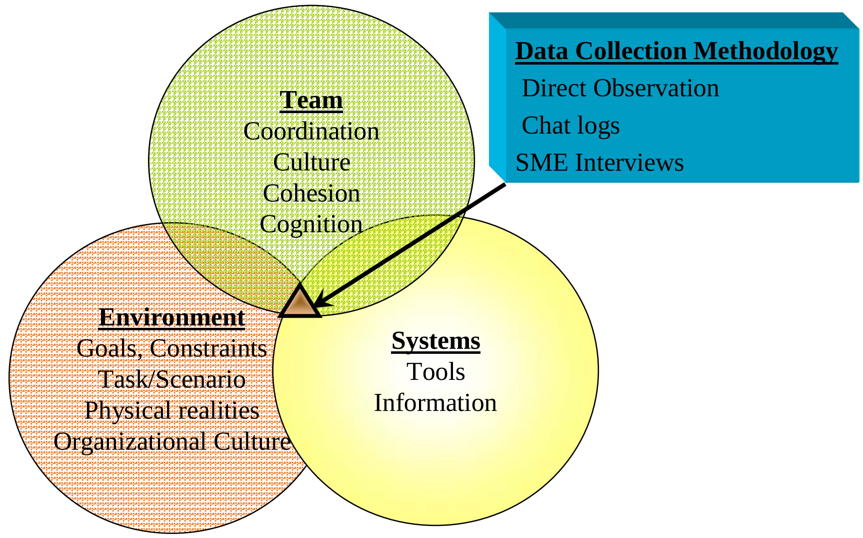

Figure 8. Data for ITSE Framework

In selecting and combining these three data collection approaches, I define six criteria that our research team strives to satisfy. **Latency** refers to the temporal delay between the data collected and the actual event (the smaller the better). **Objectivity** refers to a lack of bias or subjective filter between data and data source and relates to validity. (See Newman and Benz 1998) **Modality completeness** refers to the ability of data to capture the multiple modalities comprising the full communication spectrum (face to face, personal displays, wall displays, screen text, auditory via personal headphones, auditory via public announcement…). **Thread completeness** refers to the ability of data to capture complete threads and the full set of participants, even if distributed across different geographic locations. **Contextualization** refers to the ability to situate the data within the surrounding context, reflecting what was going on in the environment and what was going on "in their heads" at the time. Data with high contextualization can help reveal why an event or activity occurred. **Social cue capture** refers to the ability of the data to capture human-to-human interactions reflecting emotions, social hierarchy, and other social cues. Figure 9 color codes the performance of the three data types in terms of the six desired characteristics. Green indicates that the method of data collection is *usually very good* on that dimension, yellow indicates that performance is *fair or varies widely*, and red indicates that it is *usually poor*.

	Chat	Observation	Interview
Latency	G	G	R
Objectivity	G	Y	R
Modality completeness	R	G	Y
Thread completeness	G	R	Y
Contextualization	R	Y	G
Social cue capture	Y	G	R

Key: **Green** = usually very good
Yellow = fair or varies widely
Red = usually poor

Figure 9. Strengths and Weaknesses of Data Gathering Triad

Data from chat logs is particularly strong on the dimensions of latency, objectivity, and thread completeness. It is captured word for word as it occurs in real time so there is no bias or time lag between what occurred and is recorded. The clear documentation of senders, recipients, and timing allows for the re-creation of collaborative threads, from beginning to end. But chat logs typically offer a limited view into what was going on in the surrounding environment at the time of the discussion, or what thoughts may have motivated certain questions or trains of thought. Chat logs obviously do not reflect other modes of communication.

Direct observation, on the other hand, is valuable in terms of providing an opportunity to observe the full communication spectrum, from individuals typing into chat windows to face-to-face discussions and phone calls. Another strength of observational data is the ability to detect and document social cues that can reveal emotions, trust, deference, or confusion. Like chat, the latency of the data is negligible. A primary disadvantage of directly observing operators in the field, however, is that the observer cannot possibly attend to all team members and all activities at once; it is very difficult to capture an entire collaborative thread using this approach.

Interviews with experienced operators excel at contextualization, offering a venue for revealing some of what was going on in an operator's mind at the time of a particular activity. We can ask questions whose answers would be impossible to infer from observation or chat logs, such as "What prompted you to ask for that information at that point? How did you know to share the information with those particular individuals? How did you reconcile those conflicting pieces of information? Why did you need to double-check that particular source?" Interviews are also valuable for filling in context surrounding a particular collaboration or other event. Experts often provide insights based on their years of domain experience. However, interview data is less desirable in terms of latency and objectivity, and it does not provide many social cues since it focuses on one individual at a time. Figure 9 summarizes the pros and cons of the three types of data, and illustrates how combining the three can fill the gaps and achieve all of our objectives for our data.

Section 10

Summary

In complex and dynamic military domains such as Time Sensitive Targeting, human performance, the effectiveness of supporting systems, and the decision-making environment are strongly interdependent. Team decision making and other collaborative behaviors cannot be characterized in isolation, but rather occur with the support (or hindrance) of tools and as influenced by important tasks, goals, and constraints present in the decision-making environment. The proposed "Interdependent Team, Systems, and Environment" (ITSE) Framework was developed to guide data collection and subsequent analysis of team decision making in the FY04 Air Force Mission Oriented Investigation and Experimentation (MOIE), "Improving Time-Sensitive Team Decision Making." This research effort studied teams of operators in realistic time-sensitive venues to understand what kinds of tasks and functions teams are performing, why the tasks are so challenging, how they are currently done, and how to better support team performance.

This paper described the ITSE Framework, in which the components of Team, Systems, and Environment are depicted as overlapping spheres in a Venn diagram to highlight their *interdependencies*. Real time team decision-making behaviors are embedded at the dynamic intersection of those three components. As the team, their supporting technologies, and the goals and constraints from the environment interact, behaviors and phenomena emerge that could not necessarily be predicted. Teams *adapt* their collaborative and decision-making processes, and the way they use available technologies, to real-time challenges in their environment. Given MITRE's System Engineering role, this paper devoted particular attention to the interdependencies between systems and people. Richer understanding of how and why particular teams choose to use – or ignore – a particular system capability, under particular conditions, can inform system engineering efforts to achieve an effective balance between the roles for humans and the roles for systems. This is a key goal of computer-supported human decision making.

Lastly, this paper described the complementary types of data (direct observation, chat logs, and interviews) that were used by the MOIE research team to analyze collaboration in time-sensitive environments. A color-coded matrix summarized desired characteristics of these data and the relative strengths and weaknesses of each. An appropriate *combination* of these three types of data addressed the desired characteristics and captured many of the Team, Systems and Environment interdependencies put forth in the ITSE framework. Work continues in FY05 to explore and model collaboration beyond the Time Sensitive Targeting domain; the proposed framework will be tested and expanded.

As the focus shifts towards enterprise-level system engineering and solutions, the complexity in decision-making environments becomes a priority. Neither human cognition and collaboration, nor information technologies, can meet the challenge alone. Future work will explore the ways in which human cognition and information technology can complement, leverage, and augment each other, producing effective emergent capabilities in response to complexity.

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Glossary

ITSE Interdependent Team, Systems, and Environment
MOIE Mission Oriented Investigation and Experimentation
NCA National Command Authority
OEF Operation Enduring Freedom
OIF Operation Iraqi Freedom
ROE Rules of Engagement
TST Time Sensitive Targeting