COMMUNICATION OVERHEAD: THE HIDDEN COST OF TEAM COGNITION

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To function effectively, a team must act as an information-processing unit, maintaining an awareness of the situation or context in which it is functioning and acquiring and using information to act in that situation. This *team cognition* differs from individual cognition, of course, because each team member acts as an individual information processor. For a team to act in concert to achieve common goals, the team must have shared information about both the situation and the other team members. Team cognition thus requires communication-a process that has no direct analog in individual cognition-in order for the team to build and maintain a shared mental model of the situation. Because communication is essential to team performance, effective team cognition has a communication "overhead" associated with the exchange of information among team members. Communication requires both time and cognitive resources, and, to the extent that communication can be made less necessary or more efficient, team performance can benefit as a result.

In this chapter we present a theoretical framework that describes the relationship between team communication behaviors and team performance. Specifically, we look at how the *structure* of the team, as defined by both the nature of the team's tasks and the allocation of task responsibilities to individuals on the team, affects the coordination requirements for the team, and how those coordination requirements generate the need for communication among team members. Given a need for coordination and communication to accomplish the team's tasks, we examine how other factors such as the ability to preplan team actions affects the need to communicate to achieve effective performance. The intent is to show a linked pattern of relationships that flow from the nature of the team's tasks and the structure of the team through a series of intermediate variables such as the need for coordination, the need for mutual awareness among team members, the need for communication, and the efficiency of that communication, to affect the team's performance.

The theoretical framework that is presented has been developed over a number of years through an iterative process of top-down development of theory and bottom-up examination of empirical results. Theories can guide measure development by suggesting what it is important to measure. In contrast, process measures that have been empirically shown to be associated with team performance can shape theory by identifying patterns that the theories must explain. Theoretical explanations for observed relationships among phenomena can be used to extend empirical findings to predict outcomes in situations other than the ones that have been observed.

The framework is based on empirical patterns found in two team experiments. The first experiment focused on the design of an optimal ream structure for a Joint Task Force team, and the other examined the value of electronic collaborative planning tools in facilitating the performance of a team performing a humanitarian assistance airlift mission. Although the experiments had different purposes and were driven by somewhat different theoretical constructs, there is enough similarity in the constructs and the data to support the construction of a metaframework that links the two empirical patterns into an overall "story" about how team structure affects the communication behaviors that underlie effective team performance.

The team experiment efforts reported here were sponsored by the Office of Naval Research (ONR) and the Air Force Research Laboratory (AFRL). We would like to express our appreciation for the support and review of Willard Vaughan and Gerald Malecki at ONR and Sam Schiflett and Linda Elliott at AFRL.

The framework draws both on previous theories about the nature of team coordination and communication and on previous measures of communication behavior. We begin by briefly reviewing both theory and measures, pointing out how our work builds on and extends prior studies. Next we present results for two different team experiments and develop two partially overlapping theoretical frameworks. Finally, we combine the two Frameworks into a single framework that is based on both sets of experimental results and discuss how this framework will help guide our future research.

THEORETICAL CONSTRUCTS AND MEASURES FOR TEAM COORDINATION AND COMMUNICATION

Coordinated action lies at the heart of effective team performance (Kleinman & Serfaty, 1989; Orasanu & Salas, 1993), and a variety of approaches have been taken to understand the nature of that coordination and the role that communication plays in coordination. A theoretical construct that has proved useful in understanding the nature of coordinated behavior is the distinction between *implicit* and *explicit coordination* (see, e.g., E. E. Entin & Serfaty, 1999; Stout, Cannon-Bowers, Salas, & Milanovich, 1999). Explicit: coordination requires that team members communicate to articulate their plans, actions, and responsibilities, whereas implicit coordination describes the ability of team members to act in concert without the need for overt communication. For implicit coordination to be successful, team members must have a shared understanding of the situation and an accurate understanding of each other's tasks and responsibilities. The term *shared mental model* is often used to describe this shared team awareness (Cannon-Bowers, Salas, &Converse, 1993; Fiore, Salas, &Cannon-Bowers, 2001; McIntyre & Salas, 1995; Orasanu, 1990).

It is well understood that the advantages and disadvantages of implicit and explicit coordination (and, hence, the need for a shared mental model among team members) depend on the nature of the task and the task environment (Fiore et al., 2001). In aviation environments, for example, the failure to communicate explicitly has been linked to failures and accidents (Foushee, 1984). On the other hand, we have suggested in prior work (Serfaty, Entin, &Johnston, 1998) that the ability to coordinate implicitly can provide an advantage to teams during periods of intense task load by reducing the communication overhead needed for coordinated action. Implicit coordination is associated with effective performance if, and only if, team members have an accurate understanding of each other's needs, responsibilities, and expected actions; and communication may be necessary to build that understanding. In studies of the relationship between aircrew communication patterns and effective performance, Orasanu (1990, 1993; Orasanu & Fischer, 1992) found that effective aircrews alternated between implicit and explicit coordination, sing communication during periods of relatively low task load to prepare and plan so that they could coordinate implicitly, based on an accurate shared understanding, during high-demand periods.

Coordination and Communication Measures

Because of the critical role that communication plays in a team's ability to achieve coordinated action, the measurement and analysis of communication behaviors have been an ongoing focus of team research. One useful approach has been the development and validation of rating scales for assessing the quality of communication behaviors in the team (Johnson, Smith-Jentsch, & Cannon-Bowers, 1997; Smith-Jentsch, Zeisig, Acton, & McPherson, 1998) and the development of behaviorally anchored rating scales for communication behaviors that ate tied to specific scenario events (Dwyer, Fowlkes, Oser, Salas, &Lane, 1997; Fowlkes, Lane, Salas, Franz, & Oser, 1994). Other methods have categorized communications by type, based either on post hoc analysis of video, audio, or text records (e.g., Orasanu, 1990) or on real-time categorization performed during experiments or exercises (e.g., Serfaty et al., 1998) to analyze the relationship between the number of communications of different types and team performance. Some recent approaches have focused on sequential analysis of communication using statistical sequential analysis techniques (Sanderson & Fisher, 1994) to identify communication patterns such as feedback loops (Bowers, Jentsch, Salas, & Braun, 1998). Automated text processing technology such as latent semantic analysis (Landauer, Foltz, & Laham, 1998) has been used to identify sequential communication patterns without the need for extensive hand coding of communications data (Kiekel, Cooke, Foltz, & Shope, 2000).

Over the past decade, we have developed and used several measures, described below, that explicitly link the team's knowledge about each other and about their shared tasks (their team cognition) with the frequency and type of their communications. These measures are based on the theory that shared awareness among the team members (i.e., a shared mental model) results in the ability to coordinate implicitly, resulting in more efficient communication (i.e., a lower communication overhead for team cognition).

Anticipation Ratio

The anticipation ratio is a measure of communication efficiency that has proved to be associated with effective team performance for a variety of different types of teams (E. B. Entin & Entin, 2000; E. B. Entin, Entin, & Serfaty, 2000; E. E. Entin, 1999; E. E. Entin & Serfaty, 1999; E. E. Entin, Serfaty, & Deckert, 1994; E. E. Entin, Serfaty, & Kerrigan, 1998; Serfaty et al., 1998). The anticipation ratio measure calculates the ratio of the number of communications transferring information to the number of communications requesting information. Values greater than one indicate that team members "pushed" (sent) information more frequently than they "pulled" (requested) information, and that they anticipated each other's needs for information without being asked.

Mutual Organizational Awareness

We have also developed and used measures of *mutual organizational awareness* within the team (E. B. Entin & Entin, 2000) that we expect to be associated with higher levels of team performance. These measures assess the extent to which each team member had an accurate understanding, at selected points in time, of the tasks being by the other team members and can be viewed as indicators of the extent to which the team had a shared mental model of each other's activities. Our mutual awareness measures typically focus specifically on awareness of the activities of each of the team members at selected points in the scenario, in contrast to team situation awareness measures that typically have a broader focus, including a shared awareness of external scenario events and a shared understanding of the team's mission or goals (e.g., Bolstad & Endsky, 1999, 2000). Note that we use the term *organizational* here to describe mutual understanding within the context of the team and their task environment rather than within the broader scope of an entire organization.

Our theoretical explanation for the expected association of the anticipation ratio and the mutual awareness measures with team performance, and with each other, is based on the theory and findings concerning shared mental models and implicit coordination discussed earlier. Teams that have a more accurate awareness of each other's roles and actions can communicate more efficiently-more frequently transferring appropriate information without being asked. The ability to effectively push information reduces the communication overhead for the team because only one message, rather than two, is needed for information transfer. This communication efficiency reduces workload and can result in better performance. The reduction in the time and resources required for communication is especially important when the team is experiencing periods of heavy task loading (Serfaty et al., 1998; Urban, Weaver, Bowers, & Rhodenizer, 1996).

THE ROLE OF TEAM STRUCTURE IN TEAM PERFORMANCE

We have been involved for the past 6 years in a research program, sponsored by the Office of Naval Research, examining innovative team structures and organizational architectures and their relationship to team performance. A major contribution of this Adaptive Architectures for Command and Control (A2C2) program (Serfaty, 1996) has been the development of methods for designing team structures that are optimally suited to the team's mission (Levchuk, Pattipati, & Kleinman, 1998; MacMillan et al., 2001). Participation in the A2C2 program has given us a sense of how the design of a team's structure affects the team's need to coordinate for effective performance and how the need for coordination affects the communication that is necessary for team cognition. *Team structure*, in this context, refers not just to the lines of authority in the team (who reports to whom) but also to how the team divides its tasks and responsibilities and controls its resources (including information) to perform its mission.

We turn next to a discussion of two of our experiments on team structure, using the empirical relationships that were found in each experiment to construct an explanatory framework that links team structure to team performance through its effects on coordination and communication.

EXPERIMENT 1: JOINT TASK FORCE COMMAND TEAM WITH A STRUCTURE OPTIMIZED FOR ITS MISSION

The first experiment compares team performance, coordination, and communication behaviors under two different team structures, one that was optimized for the mission and one that reflects a more traditional Joint Task Force (JTF) organizational structure.

Optimized and Traditional Team Structures

As part of the AZCZ research program, a team at the University of Connecticut (Levchuk, Pattipati, & Kleinman, 1998, 1999) developed an organizational structure for a JTF team optimized for accomplishing a mission that involved an air- and sea-based operation to regain control of an allied country that had been taken over in a hostile invasion by a neighboring country. The mission involved the coordination of land-, sea-, and air-based forces to perform a sequence of operational tasks (e.g., take the beach, advance on the airport, take the airport) in the face of opposition by the enemy. Many OF the tasks were sequentially interdependent (i.e., one had to be completed before another could be started), and most required the simultaneous use of several different types of resources (e.g., sensor and weapon platforms) for successful completion. The mission was to be accomplished by a six-person JTF command team.

The optimized team structure developed for the experiment was based primarily on two optimization objectives: simultaneously minimizing the coordination required to accomplish the mission and balancing workload across the team. These multiple objectives act to constrain each other, because the workload-balancing objective prevents the assignment of all tasks to only a few team members to minimize the coordination requirements.

Coordination is defined here by the need for team members to combine the resources under their control to successfully accomplish each task. Because almost all tasks in the mission required the use of multiple types of resources, reducing the need for coordination resulted in an organizational structure in which each team member controlled most, if not all, of the resources needed to accomplish a specific task. Team members were therefore able to act independently to accomplish many tasks because all of the resources needed for the task were under their direct control. In the experiment, this optimized organizational structure was compared with a more "traditional" JTF team structure, developed by subject matter experts, in which similar resources were controlled by the same node without explicit consideration of the need to coordinate their use in the mission.

The optimized team structure in this experiment allocated the team's resources so that team members could act more independently, thus reducing the need for coordination. One might argue that, at the extreme, such a design approach would result in a collection of independent individuals that was no longer a team in the usual sense of the word. The constraints of the team's mission were such that this was not a possibility, however. Many of the team's tasks could not be done independently by one team member because of the workload associated with them. Even under the optimized design, there was considerable need for coordination-it was simply less under the optimized structure than under the traditional design.

Performance Differences Under the Two Structures

The two team structures were "played out" in a simulation-based experiment, with *10* six-person teams of military officers From the Naval Postgraduate School in Monterey (E. E. Entin, 1999). Each team participated under both architectures, with the order counterbalanced to control for learning effects. Two types of summary measures were used in the experiment simulation-based measures, which come directly from the simulation testbed, and observer-based measures, which were prepared by subject matter expert observers rating team behavior during the experiment sessions. For both types of performance measures, the performance of the six-person team using the structure that had been optimized for the mission was superior to the performance of the six-person team using the more traditional team structure that was developed by subject matter experts. The mean for the mission outcome measure under the optimized structure (M = *83.7,* SD = 2.14) was significantly higher than the mean for the traditional structure (M = 78.5, SD = 5.21), t(16) = *1.82*, p < *.05*. The mean for the observer's overall rating for the optimized structure (M = 5.32, SD = *0.53)* was also significantly higher than the mean for the traditional structure (M = 4.33, SD = 0.73), *t(17)* = 2.26, *p* < *.05*.

Effects of Structure on Coordination

The optimized team structure was designed to achieve its results by minimizing the need for coordination (defined as the need for team members to work together to accomplish a task because each one controlled different resources needed for the task), and the results show that it was successful in this goal. Teams using the optimized structure achieved superior performance while taking significantly fewer coordination actions during the mission, as measured by the coordination rate. The mean coordination rate for the optimized structure *(M* = 0.66, SD = 0.22) was significantly lower than the mean for the traditional structure (M = 1.12, SD = 0.31), t(17) = 3.55, p ***c*** .05. As might be expected given the lower need for coordination, there was also significantly less communication (a lower communication rate) for teams using the optimized structure (M = 6.30, SD = 1.53) than for teams using the traditional structure (M = 7.61, SD = 1.82), t(18) = 1.71, p < .05.

Communication Anticipation Ratio

The optimized team structure also seems to have resulted in more *efficient* communication as measured by the anticipation ratio. The mean for the optimized structure (M = 4.21, SD = 1.91) was significantly higher than the mean for the traditional structure (M = 2.67, SD = 1.26), t(17) = 1.72, p ***c*** .05. This measure is based on a classification of verbal communications by the team members into information requests and information transfers (as distinguished from other categories), computing a count of each type and calculating the ratio of the latter to the former. Under the optimized structure, team members communicated less overall, and relatively more of those communications were information transfers rather than requests for information.

Mutual Organizational Awareness

Associated with the higher anticipation ratio, team members in the optimized structure had a more accurate awareness of the tasks being performed by other members of the team. The accuracy of the team's mutual organizational awareness was calculated on the basis of the results of a questionnaire administered to participants after each experiment session. Participants were asked to "think back" to a specified memorable point in the scenario (e.g., the team had just completed taking the north beach) and to name the task they were performing at that time using 12 predefined task categories as well as naming the tasks that each other team member was doing at that time. The average agreement between participants' self-ratings of tasks performed and the ratings of the other team members provides a measure of how accurately the team members as a whole understood what each of the other team members were doing. The percentage of tasks correctly estimated in the optimized condition (M = 37.4, SD = 14.57) was significantly higher than the percentage correctly estimated in the traditional structure (M = 24.5, SD = 10.23), t(17) = 1.94, p ***c*** .05.

Task Load Index Workload Ratings

The workload of the team was assessed through the Task Load Index (TLX) self-report instrument (Hart & Staveland, 1998), with individual scores combined into a team workload score. To determine if the optimized team structure reduced workload, we made comparisons of the TLX data across conditions. The data show that the mean TLX score in the optimized team structure (M = 11.84, SD = 1.59) was lower than the mean for the traditional structure (M = 13.18, SD = 1.47), although the difference was only marginally significant, ~(17=) 1.52, *p* < ,075, one-tailed. Note that a one-tail test is appropriate given that the optimized team structure was specifically designed to decrease communication overhead that is related to subjective workload.

Discussion: Theoretical Framework for Results of Experiment 1

In this experiment, a lower need for coordination and a lower communication rate were associated with better team performance. We suggest that a complex pattern of factors centered around communication overhead produced this result, as shown in Figure 4.1. Task interdependence was defined by the mission-a given in the experiment-and was quite high. Almost all of the tasks required multiple types of resources for completion, and many could not be accomplished until others were completed. Task interdependence and team structure jointly determine the need for coordination within the team, defined as the need to simultaneously use resources controlled by multiple individuals to accomplish a task. The need for communication follows from the need to coordinate. The optimal team structure resulted in less need for coordinated use of resources to accomplish tasks and, therefore, less need to communicate.

Team cognition requires communication, but communication has a cost in time and effort. Because less communication was required to accomplish the mission successfully under the optimized structure, team members experienced lower workload (as measured by the TLX score) and were able to devote more effort to understanding the roles and actions of the other team members (increased mutual awareness). This improved understanding led to more efficient communication (anticipation ratio) based on a better mental model of teammates' activities. Overall, team members in the optimized structure communicated less, and, when they did communicate, they communicated more efficiently, contributing better overall team performance.

EXPERIMENT 2: HUMANITARIAN ASSISTANCE AIRLIFT TEAM USING FUNCTIONAL AND DIVISIONAL TEAM STRUCTURES

This second experiment provides another perspective on the effects of team structure on the communication necessary for effective ream cognition (Miller, Price, Entin, Rubineau, & Elliott, 2001; Price, Miller, Entin, & Rubineau, 2001). The experimental task was a humanitarian airlift mission in which teams of three participants planned and carried out an air drop of food and medical supplies at predetermined target locations (refugee sites).

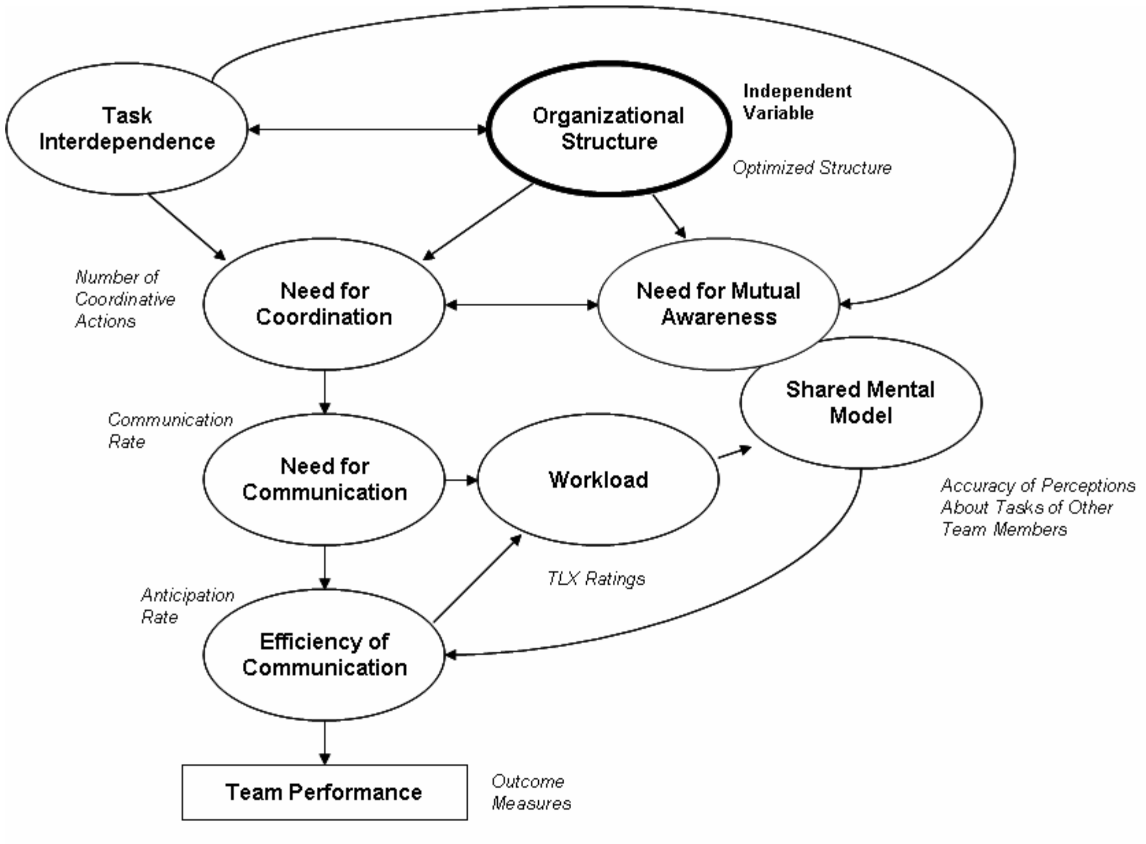

Figure 4.1. Theoretical framework for results of Experiment 1 (measures shown in italics). TLX =Task Load Index.

There were three types of aircraft involved: food supply planes, medical sup. ply planes, and Combat Air Patrol (CAP) planes that served as a defensive escort for the mission. The team coordinated to plan and carry out the airlift. Thirty-six university students served as participants in teams of three.

Divisional and Functional Organizational Structures

Like Experiment 1, this experiment also tested different organizational structures and examined the effects of team structure on team processes and performance. Two organizational structures were used: a functional structure and a divisional structure. In a divisional structure, work units are constructed so that each unit possesses the skills or resources required to complete a product or task. Work units are therefore capable of working relatively autonomously. In a functional structure, work units focus on one type of skill or resource. Thus multiple units are required to complete most tasks or products.

The distinction between divisional and functional structures in industry dates back to the organizational behavior distinctions and changes made in the 1980s in the context of adaptability to market demands and competition. In particular, when production began to require more rapid adaptation to deal with competitors, organizational design theorists began to describe the benefits of moving from the strict hierarchies associated with the divisional structure common to most

U.S. firms. With the move to product focus, although losing the economies of scale, firms were able to address competition by rapidly adapting to market demands.[1]

Following the team research of Hollenbeck et al. (1999), we applied the conceptual differentiation between functional and divisional structures, originally developed in a broader organizational context, to the functioning of a three-person team. In the experiment, the divisional structure was defined by having each of the thee team members control some of each of the three types of planes needed for the airlift. In the functional structure, the food, medicine, and CAP lanes were controlled by three different individuals so that all tasks required coordination.

Note that the divisional and functional structures have some similarity to the two structures described in the previous experiment, with the functional structure being more similar to the traditional JTF structure, and the divisional structure more similar to the optimized JTF structure. However, the optimized JTF structure allocated resources to individuals on the basis of the requirements of the mission, whereas the divisional structure simply allocated some resources of each type to each team member. In this experiment, the availability of resources and the amount of resources allocated to each team member were key factors that affected the need for coordination (pooling of resources to accomplish tasks) under the two structures. Organizational structure was varied as a within-teams variable in the experiment, with each team performing under both structures in counterbalanced order.

Hollenbeck and associates (Hollenbeck et al., 1999; Moon et al., 2000) have found that the effectiveness of teams using the divisional and functional structures depends on the nature of the tasks to be accomplished and the uncertainty in the situation. When the situation is uncertain or unpredictable, the divisional structure works well. In more predictable situations, the functional structure is more efficient.

We suggest that task interdependence and adequacy of resources are also key factors that *interact* in the effectiveness of the two structures. If team members in the divisional structure have adequate resources to handle tasks on their own, then this structure, which minimizes the need for coordination, should be more effective. If team members in the divisional structure lack sufficient resources to handle tasks alone, however, then they will need to coordinate and may be at a disadvantage because of their lack of experience in coordination. In the functional structure, team members must always coordinate to accomplish tasks that require multiple types of resources. This structure will therefore generate more need for coordination than the divisional structure, if the team members in the divisional structure have adequate resources to handle the tasks independently.

The interaction of the mission and the organizational structures and the resource allocation in the experiment was such that many of refugee sites, but not all of them, could be handled independently by the team members in the divisional condition. For some sites, none of the team members in the divisional condition had sufficient resources to handle the site by themselves and coordination was required. In the functional condition, the team members always needed to coordinate to handle a site.

Mission Planning With Electronic Collaborative Tools

A second major purpose of the experiment, in addition to testing team structures, **was** to evaluate the effect of electronic collaborative planning tools on the planning processes of the team. Planning medium-defined as the presence or absence of electronic tools for collaborative planning-was a second independent variable in the experiment, varied as a between-teams variable. In one condition, the participants conducted their planning session using an electronic

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[1] We are indebted to Steve Fiore and Eduardo Salas for this historical perspective.

whiteboard showing a map of the targeted area for the airlift. As they developed their plan, they were able to capture it by malting electronic annotations on the shared whiteboard. In the other condition, participants used a paper map covered with a clear plastic sheet to conduct map-and-grease-pencil planning similar to that currently conducted in many military operations. The major advantage of electronic collaboration tools is, of course, their ability to support collaboration for teams who are physically distributed in location. In this initial experiment, however, the team members in both conditions were physically colocated to assess the effects of the tools on the planning process independent of the location of the team members.

Performance Differences by Condition

The performance of the teams in the experiment was measured by task accuracy: success in delivering the required amount of supplies to each of the refugee sites. Percentage task accuracy was measured by the percentage of times that the team managed to deliver 100% of the needed supplies to each of the refugee sites. With this measure, team performance was more accurate for the functional (M = 83.9, *SD* = 15.04) than for the divisional condition (M = 77.14, *SD* = 17.28), *t(l0)* = 1.92, p < .05. Using a slightly different measure (average percentage task accuracy), task accuracy was also higher when the electronic whiteboard was used for planning (M = 52.8, *SD* = 4.62) than for the paper, based planning condition *(M* = 48.04, *SD* = 7.03), t(10) = 1.83. p < .05.

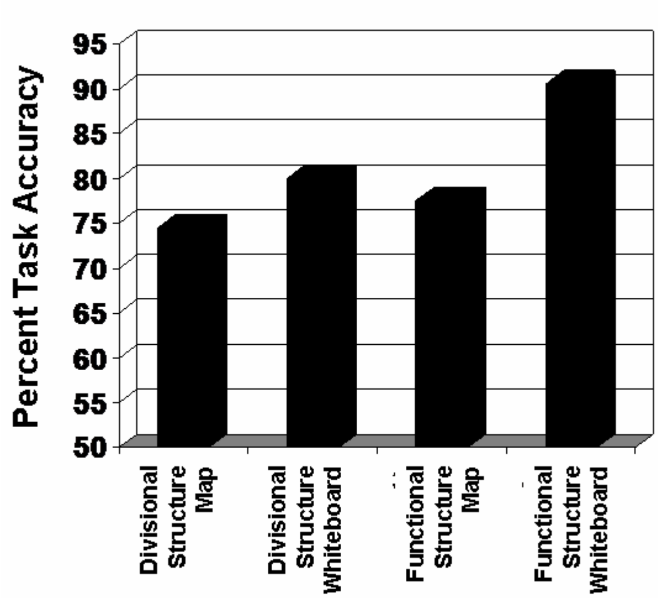

Figure 4.2. Team performance (percentage task accuracy) by divisional and functional team structure and by planning condition.

We have some evidence, as shown in Figure 4.2, that the electronic planning medium was more advantageous for teams in the functional condition. The performance of the functional teams using the electronic whiteboard (*M* = 90.31, *SD* = 7.67) was somewhat higher than the performance of functional teams using the paper map (*M* = 77.49, *SD* = 18.45), although the difference is only marginally significant, $t(10) = 1.38$, $p < .10$.[2] There was no significant difference by planning medium for teams using the divisional structure.

Coordination Success

Analysis of the coordination patterns and the communication during planning for the two team structures sheds some light on these effects. Overall, the functional structure required that team members coordinate use of their resources more frequently than the divisional structure. However, the requirements of the mission and the organizational structure interacted to require a certain amount of coordination in the divisional structure-that is, there were numerous sites for which no one team member had the resources needed to handle the site independently. When team members in the divisional structure needed to coordinate, they did so with much less success than teams in the functional structure, as measured by the percentage of the team members required co complete a coordinated task who actually participated in that task, For example, if the resources of two team members were needed to complete the task, and only one team member attempted to perform the cask, the value of the measure is 50%. The mean for the coordination success measure (percentage of required team members who participated in each task) was higher for the functional structure ($M = 95.36$, $SD = 4.30$) than for the divisional structure ($M = 84.35$, $SD = 10.77$), $t(10) = 3.63$, $p < .05$.

The divisional structure, as it was implemented with resources available, and given the mission requirements, seems to have put the teams at a disadvantage in this experiment. Overall, the divisional team structure required less coordination than the functional structure, but this did not give the structure an advantage for the mission. The coordination that was required for the divisional teams seems to have been more difficult for them. The functional teams achieved better performance than the divisional teams even though they needed to coordinate more frequently to achieve that performance.

Collaboration During Planning

In this experiment, we implemented a measure of the extent to which the teams communicated in a collaborative manner during planning. During the planning process, both the verbal and written (graphic as well as text) communications of the team members were coded by number and type. Communications during planning were later categorized into those that represented collaborative intentions (e.g., paraphrasing or acknowledging others' ideas) and those that did not (e.g., proposing a new idea). Using this measure of collaborative communication during planning, we found that the planning sessions conducted using the electronic whiteboard involved more collaborative communication ($M = 84.02$, $SD = 6.52$) than those conducted with the paper map ($M = 79.33$, $SD = 5.18$), $t(10) = 1.74$, $p < .05$. This was the case for both organizational structures.

We suggest that the more collaborative planning process that was associated with the use of the electronic whiteboard contributed to the team's ability to coordinate successfully and, therefore, to the better performance of the teams in the functional structure/electronic whiteboard condition. The collaborative planning process, as supported by the electronic whiteboard, gave the functional teams an advantage in carrying out their coordinated activities during mission execution. The divisional teams, in contrast, apparently did not benefit From collaborative planning in such a way that they were able to carry out their coordinated tasks effectively-they performed less well during the mission.

[2] These means combine the effects of a within-teams variable (structure) and a between-teams variable (planning condition). We used a pooled error term to test these contrasts, following the procedures of Winer (1962).

Discussion: Theoretical Framework for Results of Experiment 2

In Experiment 2, we saw again how the team's structure, in particular, the allocation of resources to team members, interacted with the resource demands of the tasks to be performed by the team to affect the need for coordination among the team members. However, there was an additional factor in this experiment that we had not previously studied in assessing the effects of structure on performance-the presence of an electronic planning tool that changed the collaborative interaction of the teams during the premission planning process. Collaborative planning played a key role in allowing the teams using the functional structure to accomplish the coordination required. Teams that planned using the electronic whiteboard exhibited more collaborative communication during their planning, and this collaboration during planning was apparently more beneficial to the teams in the functional structure that needed a high degree of coordination to complete the mission successfully.

Figure 4.3 shows a theoretical framework for understanding the results of Experiment 2. As in Experiment 1, we suggest that the organizational structure and the interdependence of the tasks drive the need for coordination. In this experiment we have a direct measure of the success of the coordinated actions, and more successful coordination is associated with better team performance as measured by task accuracy. We suggest that the presence of the electronic whiteboard, through its effect on increasing collaborative communication during planning, contributed to that coordination success. The need for coordination was affected by the nature of the mission tasks and the team's structure, and the success of the needed coordination was affected by the nature of the team's preplanning activity.

Effective preplanning has been shown to increase a team's shared mental model and subsequent coordinated team performance (Stout et al., 1999), and we expect that the more collaborative planning process that was facilitated by the electronic whiteboard may have led to a better shared mental model among the members of the functional teams (this was not directly measured in Experiment 2). We also expect that the functional teams may have been able to communicate more efficiently during the mission because of their better shared mental model, and that this efficiency of communication allowed them KO achieve a higher level of performance even though their team structure required more coordination than was needed under the divisional structure. Therefore, we would expect to see a higher anticipation ratio for teams using the functional structure and the collaborative planning tool. The anticipation ratio was not measured in this experiment, however.[3]

[3] Communications data (counts by typed of communications) were coded by observers (in real time) only during pre-mission planning, not during mission performance.

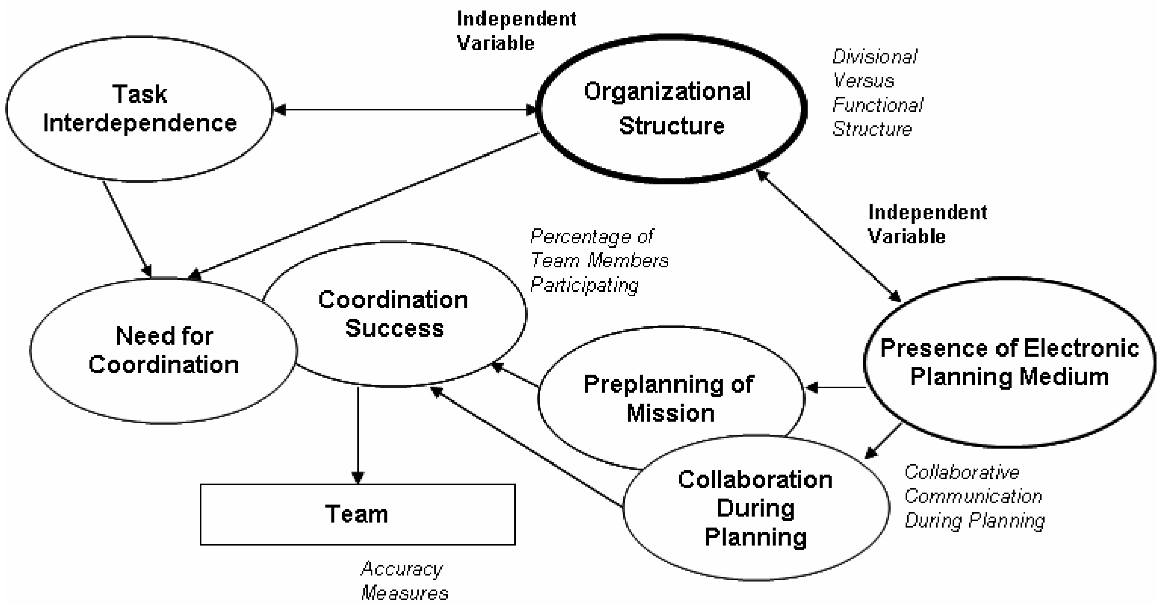

Figure 4.3. Theoretical framework for results of Experiment 2 (measures shown In italics).

SUMMARY: THEORETICAL FRAMEWORK LINKING TEAM STRUCTURE TO COMMUNICATION AND PERFORMANCE

In both of the experiments described here, we saw how the organizational structure used by the team (in particular, the way that the team's resources were allocated and controlled) interacted with the requirements of the tasks to be performed to generate requirements for coordination. In Experiment 1, the available resources were adequate for implementing an optimized structure that allowed team members to function relatively independently, reducing the coordination needed for successful performance. In Experiment 2, resources were not adequate for team members in a divisional structure to handle all tasks independently. Although the overall need for coordination was lower in the divisional structure (fewer tasks required the coordinated use of resources), the teams using this structure performed less well than teams using a structure that required more coordination.

We believe that the workload associated with communication (the communication overhead) was a critical factor in the performance of teams under the different organizational structures. In the first experiment, the optimized structure successfully reduced the need for coordination and the volume of communication necessary to achieve this coordination. We suggest that the reduced workload associated with less need for communication allowed team members to develop a better awareness of the tasks of others on the team (better mutual awareness) and, based on that awareness, to communicate more efficiently (higher anticipation ratio). Teams communicated less frequently, and also more efficiently, in the optimized structure.

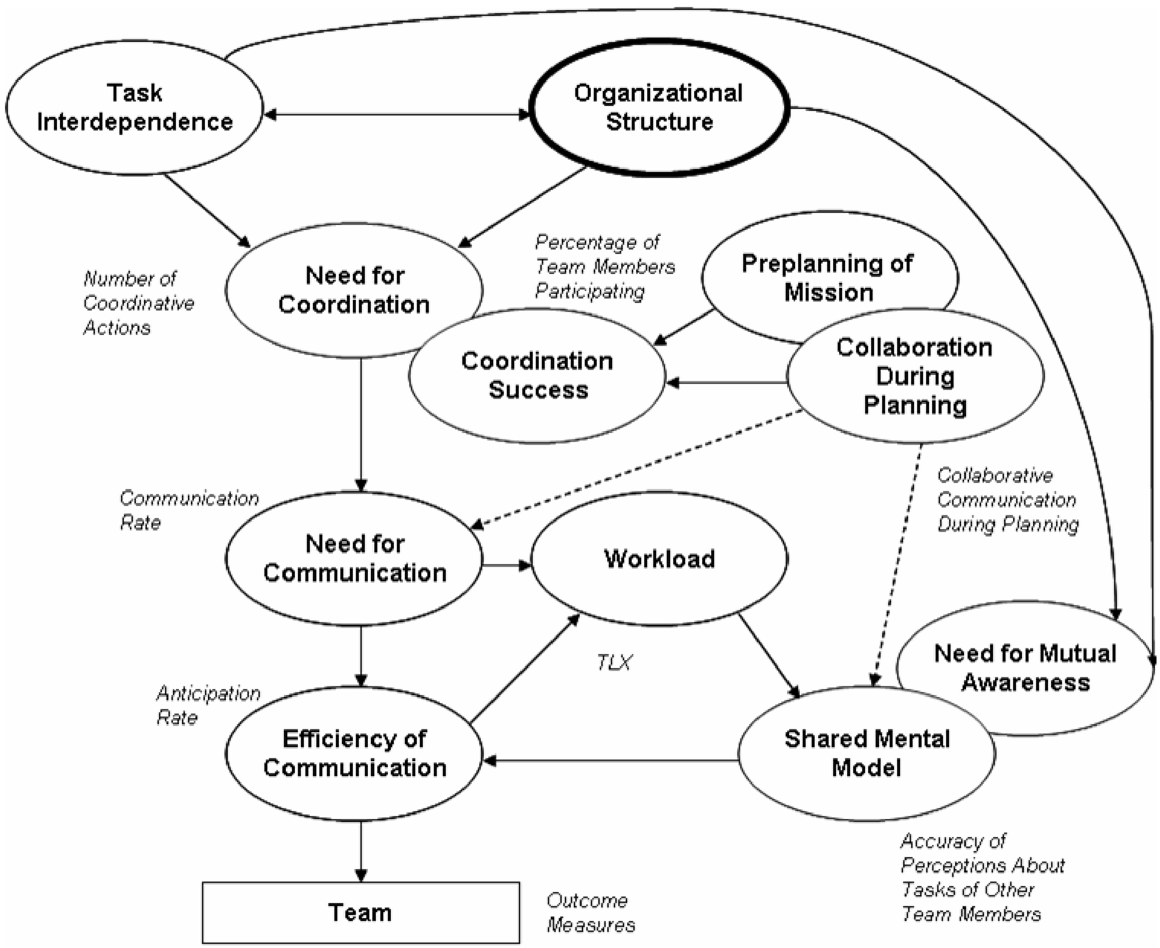

Figure 4.4. Framework linking team structure to communication efficiency (dotted lines indicate links not yet supported by data).TLX = Task Load Index.

In the second experiment, we saw effects of both collaborative premission planning and team structure on performance. Even though teams using a functional structure needed to coordinate more to accomplish the mission, they were able to achieve a higher level of performance, apparently as a result of more collaborative premission planning. We suggest that collaborative premission planning may have increased the team's shared mental model and mutual awareness, allowing them to communicate more efficiently, although this was not directly measured in Experiment **2.**

The two experiments reported in this chapter examined different factors and used different measures and so are able to provide empirical evidence to support two different, but overlapping, theoretical constructs. In Figure 4.4 we combine these two constructs into a single overall framework that shows how team structure, given a particular task configuration, affects performance through its effects on required coordination and communication overhead. The framework shown in Figure 4.4 is suggested but not yet established-it is provided as a possible explanation for the empirical relationships among variables that were found in the two experiments.

The Framework suggests the following relationships:

- The structure of the ream (in particular, the control of resources and the allocation of tasks to team members) interacts with the nature of the team's tasks to generate the need for coordination among team members and the need for mutual awareness. If the team members have the resources to act relatively independently in many situations, they will have less need to coordinate their actions and may have less need to be aware of the activities of others.
- The need for coordination drives the need for communication among team members.
- To the extent that team members need to coordinate, better mutual awareness allows them to do so more efficiently, that is, with a lower communication overhead.
- Lower need for communication and more efficient communication are associated with lower workload.
- = The ability to collaboratively preplan the mission results in better mutual organizational awareness (knowledge of tasks being performed by other team members), and this awareness allows team members to communicate more efficiently (lower communication overhead).
- = More efficient communication among team members (lower communication overhead) results in better team performance. This reduction in communication overhead can be created in multiple ways, such as by restructuring the team to reduce the need for coordination or by activities that increase mutua1 awareness and shared mental models among team members, such as collaborative premission planning.

We plan to focus our future research on the links that are suggested in Figure 4.4 but not yet empirically validated, shown as dotted lines in the figure. We have evidence that changing the team's structure affects the need for coordination, the need for communication, and the efficiency of communication; and that better mutual awareness is associated with more efficient communication (lower communication overhead). However, rearranging ream responsibilities to reduce the need for coordination may be neither desirable nor practical in many circumstances. We saw two different patterns associated with superior performance in the two experiments--one case in which the teams that needed to coordinate ***less*** during the mission performed better, and one in which the teams that needed to coordinate more during the mission performed better if they collaborated more during premission planning. We suspect that communication overhead is an important factor in these different patterns, and we need to better understand how to reduce that overhead. We believe that premission collaborative planning achieves its effect on performance by increasing the team's mutual awareness and thereby reducing communication overhead, but we do not yet have direct evidence for that belief. In the future, we hope to more firmly establish the means by which collaborative premission planning supports effective coordination during the mission.

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