Collaborative Planning and Coordinated Team Performance[1]

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Abstract

There is evidence from computer-supported collaborative work research that groupware applications can change the process of cooperative planning and can help teams plan more effectively. There is also research that indicates functional as opposed to divisional organizational structures may be more efficient when the mission is certain and predictable. We studied the effects of planning medium (i.e., paper map versus shared electronic whiteboard) and team organizational structure (i.e., functional versus divisional) on the ability of C2 teams to perform a coordination and resource allocation rich set of scenarios. Findings show that the functional organizational structure produced higher performance in terms of task accuracies, shorter times to initiate tasks, and higher coordination on task performance. The results also indicated that teams who planned each trial mission using the electronic white board enjoyed a performance advantage over those teams who planned using a paper map and markers. The implications of these findings are discussed.

Introduction

As computer technology has evolved to allow multiple individuals to work together via linked groupware applications, research has flourished on computer supported collaborative work (CSCW). This work bears directly on the goals of modern command and control (C2) development, where multiple individuals strive to coordinate actions more effectively via the use of emergent collaborative technologies. CSCW research to date has been characterized by an emphasis on the details of the supporting technology and a focus on group collaboration *within* the medium under consideration. Tasks are generally based on problem solving or consensus building as opposed to tasks that require coordination that is tightly coupled in space or time. Examples of tasks used in previous research include solving logic problems (Strauss & McGrath, 1994), and coming to consensus on an ethical dilemma (Weisband, Schneider & Connolly, 1995). In this research, we broaden the research scope to investigate the effects of computer-supported planning on subsequent performance on a coordinated team task. If computer-supported planning fosters more balanced levels of participation among team members as some research has suggested (Dubrovsky, Kiesler & Sethna, 1991; Rawlins, 1989) then

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tasks that require high levels of participation and communication by all team members should be enhanced.

Another area of research impacting C2 is the study of organizational structure. Hollenbeck et al. (1999) discuss two ubiquitous organizational structures, divisional and functional. In a divisional structure work units within an organization are constructed so that each unit possesses the skills and/or resources required to complete a product the organization produces. Such work units are capable of working relatively autonomously. An example of a divisional structure is when an organization staffs each of its geographical (regional) offices with all the resources it will need to deal with all aspects of the organization's business. This allows the regional offices to operate relatively independent of one another.

In contrast a functional structure produces work units that specialize in one aspect of a product's production. The different specialized units coordinate to produce a finished product.

Recent research indicates that no one organizational structure (i.e., divisional or functional) is optimal for every situation (Hollenbeck, et al., 1999). It is necessary to consider the human resources available and the demands within the environment to achieve the best fit. Moon et al., (2000) report that when a situation is unpredictable and uncertain, a divisional organizational structure works better than a functional organizational structure and the organizational literature seems to bear this out. A divisional structure provides each entity of the organization with a mix of organizational resources/assets. Thus, each entity is prepared to meet a myriad of situations relatively independently. If, on the other hand, the situation is relatively predictable and certain then a functional structure with specific specializations to meet specific needs/threats is more efficient. So, it appears that when faced with an unpredictable and uncertain situation, it is best for organizations to start with a divisional structure and, as more becomes known about the situation, to evolve to a functional structure.

Study Objectives

The goal of this study was to systematically observe the effects of computer supported planning and organizational structure on coordinated team performance. Performance was assessed within the context of a unique team-in-the-loop task, hosted by the Distributed Dynamic Decision-Making (DDD) simulation. The current DDD simulation and scenarios used were an abstraction of an other-than-war operation: a humanitarian relief effort. Team members were required to coordinate their efforts in order to deliver supplies to refugees while defending against hostile attacks.

Method

Participants

Thirty-six students, 24 male and 12 female, were recruited from a northeastern university to serve as participants. Twelve teams of three students each were formed and each participant was remunerated $35 for his or her participation. The mean age of all participants was 23 years (SD = 3.05). Based on a survey to elicit experience with computers/video games it was determined that the sample was reasonably computer literate: 92% of the sample reported daily use of a computer and the remaining 8% reported using a computer "a few times a week." Participants' high familiarity with computers facilitated training in the DDD simulation environment.

Experimental Design and Independent Variables

The study manipulated two independent variables: *planning medium* and *team organization*. Planning medium was manipulated as a between-subjects factor and contrasted a computer supported electronic white board with a traditional map and marker process. In the electronic white board condition each team member viewed a shared pictorial representation of the simulation environment. Team members were able to make electronic annotations on the white board and communicate verbally with one another. In the paper map and marker condition team members sat around a paper map representation of the simulation environment that was identical to the corresponding white board display. The map was covered with a clear plastic sheet and team members were free to converse verbally and annotate the map. This latter condition was assumed similar to the map and grease pencil method of planning typically used by many in the military today. Six teams were randomly assigned to the white board condition and six to the paper map condition.

Team organization was varied as a within-subjects factor and in accordance with Hollenbeck et al. (1999) contrasted a *functional organization* where each participant had one specific role for an entire airspace (e.g., defender, medical supplier, etc.) with a *divisional or distributed organization* where each participant performed multiple roles (i.e., defender, medical supplier, food supplier) throughout a trial. The independent variables were completely crossed to produce a 2x2 mixed-factorial design as shown in Figure 1. Each within-subjects condition was replicated, thus a team participated in four trials (two functional and two divisional) nested in either the white board condition or the paper map and marker condition.

		Team Organization (Within-Subjects)	
		Functional	Divisional
Level of Technology Support	Electronic White Board	6 Teams	6 Teams
	Map & Markers	6 Teams	6 Teams

Figure 1. Experiment Design

Dependent Variables

The researchers made assessments at three phases of the experiment: during the planning sessions, while the teams were engaged in a simulation trial (scenario), and after teams executed a trial. Observational data collection forms were based on real-time communication coding forms used in past experiments to capture communication activities during execution (Entin and Serfaty, 1999; Entin, 1999; Entin, 2000).The coding forms were designed to provide a structured way to capture certain theoretically interesting communication behaviors without being overwhelmingly exhaustive or overly simplistic. The point of the coding form is to strike a balance by focusing the data collector's attention on the directionality represented on the x-axis and the function, form and type of communication of the y-axis.

To use the form, the coder monitors the team's activities. Whenever one participant communicates with one or more of his/her teammates, the coder places a checkmark in the matrix-square that indicates the function, type, and directionality of the communication.

Simulation

During a simulation trial, observational data on team behaviors were collected and coded using a similar method to that used in the planning phase. Objective performance-related data was also derived from the DDD's logfiles. The observational data collected in this phase included:

- Number of total team communications
- Types of communication (questions, requests, transfers, acknowledgements)
- Content of request and transfer communications (information, action or task, resource utilization, coordination)
- Directionality of communication (from one member to all others, from one member to another member)

Data derived from the DDD simulator included:

- Task accuracy, that is, were the correct mix and number of supplies delivered to a site, averaged across all sites in a scenario. This is computed per team.
- Number of downed hostile aircraft per team
- Number of friendly aircraft lost per team

Post Execution

During the post-trial phase a modified form of the Task Load Index (Hart, and Staveland, 1988) was administered to assess individual and team subjective workload. The survey contained 13 items and used 11-point Likert response scales.

Equipment

Three networked laptop computers configured with the electronic white board application and the DDD simulator hosted the humanitarian relief scenarios. Six scenarios were used: three for each organizational structure condition (one for training and two for data collection). The experiment was carried out in laboratory space configured for electronic meetings. This facilitated the unobtrusive video/audio recording of each data collection trial.

Procedure

Scenario

To maintain a decidedly military flavor, while keeping the task appropriate for a college subject population, we adapted an existing AWACS scenario (Entin et al., 2000) to portray an operation-other-than-war humanitarian assistance mission. In this mission team members had to coordinate a "strike" mission to air drop food and medical supplies on predetermined target locations. Specifically, there were three main roles that the teams perform in order to complete the humanitarian relief scenario:

- **Food Supply Planes** were responsible for delivering food support packages to refugee sites.
- **Medical Supply Planes** were responsible for delivering medical support packages to refugee sites.
- **Combat Air Patrol (CAP)** planes flew about and determined the level of need at each refugee site. The need requirements for a majority of refugee sites were initially unknown. They were also responsible for identifying unknown aircraft as friendly, neutral, or hostile and prosecuting hostile aircraft to protect the supply planes.

The scenarios were developed to necessitate collaboration among the team members. For example, CAP aircraft were required to determine the need requirements of a refugee site before supply planes could drop the required amounts of food and/or medicine. Supplies had to be coordinated as a site might require only a single food or single medical drop, while other sites might require two of one and a single of the other. CAP also required coordination in that a CAP aircraft could only engage a single hostile at a time and some hostiles required processing by two CAP aircraft. Thus, like actual AWACS missions, it was the job of the team to coordinate and control a range of asset types to complete a complex mission, managing the overall picture through placement of surveillance assets and coordinating as a team to accomplish their goals quickly and efficiently.

Training to Use the DDD Simulation

Each team was shown a series of ten video training clips demonstrating the various capabilities of the DDD simulation. The clips consisted of video captures of the DDD simulation demonstrating how to perform a variety of actions, with voice over providing verbal instruction. The experimenters introduced each clip and then projected it onto a large screen for viewing. Team members were instructed to watch each clip and then try to perform the actions shown on their work stations. They were encouraged to ask questions at any time, and video clips were replayed if necessary to ensure that participants were comfortable performing the particular action. Following the video training, the experimenters briefly explained the DDD simulation's scoring, e.g., that the team accumulates points for each humanitarian site that is satisfied and each hostile plane that is destroyed. The participants then played a training scenario to practice the skills they had acquired in the context of a humanitarian mission.

At the conclusion of the training mission, the experimenters explained that team members would be given the opportunity to plan their mission prior to performing the data collection scenarios. For the paper map condition, team members were shown a training map and given the opportunity to practice annotating it. For the electronic white board condition, participants were given information packets describing the basic editing capabilities of the white board application and were allowed to try the various editing features on a training map loaded on the electronic white board. Training for planning was given after the practice DDD simulation training scenario had been conducted –

during our pilot trials, we observed that participants did not really appreciate the potential benefits of planning until after they had practiced on the DDD.

Protocol

The study was conducted during the Spring and Fall 2000 semesters. Each experimental session followed the same basic protocol:

1. introduction and mission overview
2. training to use the DDD simulator
3. explanation of scoring
4. training for planning (e.g., how to use the whiteboard technology)
5. planning
6. execution of scenario
7. individual and self-workload survey

Steps 5 through 7 were repeated four times for the four experimental conditions. Scripts and video training clips presented via a computer monitor were used to ensure consistent training across participants. Sessions ranged in length from 2.5 to 3.5 hours, with most sessions lasting approximately 3 hours. At the end of the experiment all participants were verbally debriefed.

Hypotheses

We have presented arguments that situations that are unpredictable and uncertain are better served by a divisional organizational structure works, whereas relatively predictable and certain situations are more efficiently handled by a functional structure. We further argue that the humanitarian relief scenarios were designed to be certain and predictable. The locations of all the sites are visible at the start of each scenario. The specific needs of the sites are unknown, but the team has the resources to learn them and there is no uncertainty, ambiguity, or attempts to mislead. The teams know there are both neutral and hostile aircraft and once identify the identities are known with certainty. Finally, all teams had an opportunity to plan for each humanitarian scenario prior to performing it. Thus, we predict that when teams use the functional organizational structure they will perform at a higher level than when they use the divisional organizational structure for the humanitarian relief scenarios.

Results

We hypothesized that, due to the relative predictability of the humanitarian task environment, a functional organizational structure would foster higher performance and coordination than a divisional organizational structure. Several performance measures were derived from the DDD logfiles (e.g., percentage of tasks completed, task accuracy, and task latency, coordination performance) to test this hypothesis. Virtually all tasks were performed by each team, rendering percentage of tasks completed as a measure moot. However, not all tasks were effectively prosecuted. A variable was derived that examined the percentage of humanitarian tasks that were completed with 100 percent accuracy for each team. A MANOVA of this variable revealed, as shown in Fig. 2, that when teams worked under the functional organizational structure they exhibited higher performance, that is, a significantly higher percentage of tasks completed with 100 percent accuracy than when working under the divisional organizational structure ($p < .045$). This result follows from the prediction that a functional organizational structure will be superior to a divisional organizational structure when the task is stable and predictable. An analysis summarized in Fig. 3, shows an effect due to medium for humanitarian task accuracy. Teams that experienced the electronic white board during the planning session exhibited higher task accuracy (i.e., used the correct mix and number of resources) than teams who used only paper maps during planning ($p < .05$). We suspect that the electronic white board produced better awareness of the situation and the task requirements than when paper maps were used.

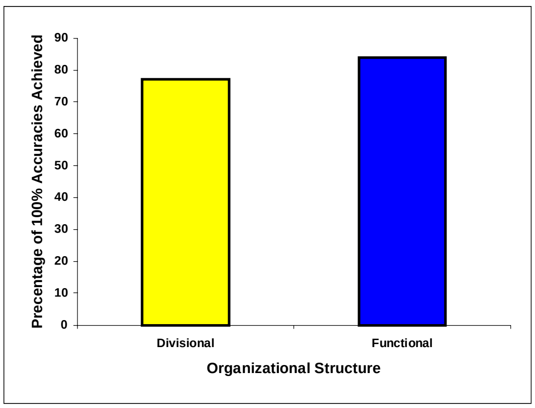

Figure 2. Percentage of 100% Accuracies Achieved for Humanitarian Task Processed for Divisional and Functional Organizational Structures

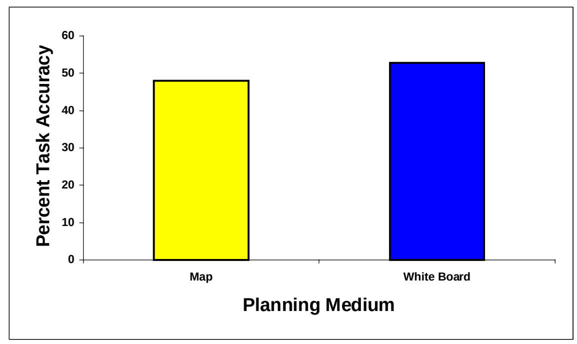

Figure 3. The Accuracy in which Humanitarian Tasks Were Performed Expressed in Percent for Paper Map and Electronic White Board Conditions

An analysis of humanitarian task latency, that is the length of the time interval from time a humanitarian task could be processed until it was processed, showed no reliable differences for either independent variable. Additional analysis of latency showed, however, that once prosecution of a humanitarian task was initiated it took significantly less time for teams under the functional than divisional organization structure to complete the task ($p < .01$). In this case, completion means from the time when the first team member started task prosecution until the last team member required to complete the task initiated prosecution. Thus, not only did teams working with the functional organizational structure perform the humanitarian tasks more accurately, they also performed them more quickly.

Turning to the hostile aircraft task we see a pattern of results that parallels that of the humanitarian task. Figure 4 shows that teams who used the white board during planning achieve a higher accuracy prosecuting the enemy aircraft than teams who used the paper maps during planning ($p < .04$). In Fig. 5 we see that when teams used the functional organizational structure they responded more quickly (i.e., shorter latency) than when the divisional organizational structure was used ($p \leq .08$).

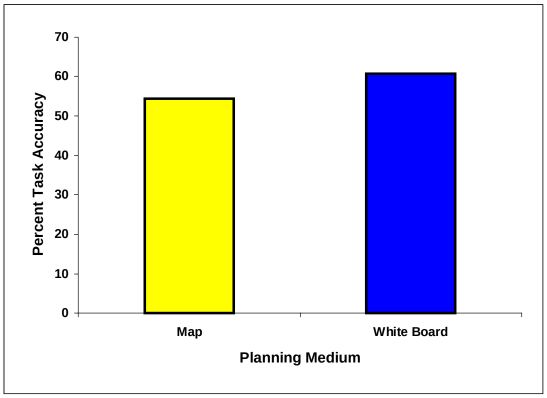

Figure 4. Task Accuracy for Prosecuting the Hostile Aircraft Expressed in Percent for Paper Map and Electronic White Board Conditions

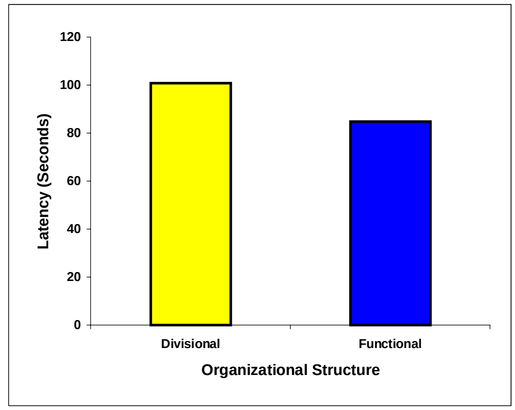

Figure 5. Latency in Seconds to Initiate Attacks on Hostile Aircraft for Divisional and Functional Organizational Structures

To assess coordination performance, we determined the number of team participants required to process each task. We then computed the percentage of team participants that actually processed the task. For example, if two participants were required, but only one processed the task a score of 50% was given. The percentages were averaged over all tasks and analyzed. A MANOVA indicated, as expected, that the functional organizational structure fostered more coordination among team participants than the divisional organizational structure ($p < .005$). The means are displayed in Fig. 6. We believe, as noted above, that the functional structure supported more communication that was conducive to coordination.

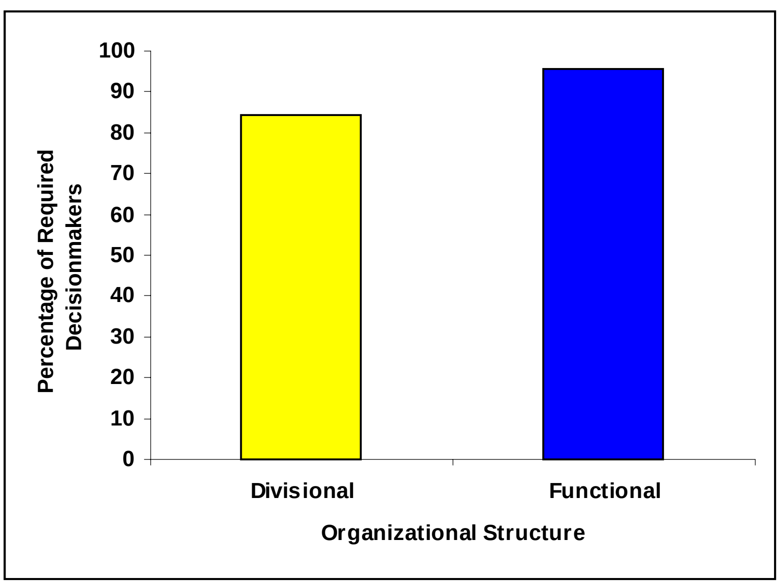

Figure 6. Percentage of the Required Number of Decisionmakers Performing Humanitarian Tasks for Divisional and Functional Organizational Structures

Discussion

As hypothesized, when teams worked under the functional organizational structure they posted higher performance in terms of task accuracies, shorter times to initiate tasks, and higher coordination on task performance. When elements of the task environment are certain and predictable as they are in the humanitarian relief scenarios, the specialization of a functional organizational structure facilitates task performance more than the generalist approach of the divisional organizational structure (Hollenbeck et al., 1999; Moon, et al., 2000). This implies that when a mission poses an uncertain and unpredictable environment it is better to employ a divisional organizational structure so that each element of the organization is more or less equipped to deal with any eventuality. As the mission becomes more known and predictable the organization will gain performance efficiency by transitioning to a more functional organization.

The results also indicated that teams who planned each trial mission using the electronic white board enjoyed a performance advantage over those teams who planned using a paper map and markers. Team members who employed the paper map and markers tended to gesture more frequently than teams using the white board, but they made almost no annotations on the map. Teams using the white board were constrained to draw on or annotate the white board if they wanted others to see. We surmise that the explicit nature of drawing out planning strategies on the white board, as opposed to the more implicit nature of gesturing (without marking the paper map) fostered a more accurate shared understanding of the plan. This in turn translated into higher performance for those teams planning with the electronic white board. These results have another important implication. Traditional paper maps and markers cannot support distributed mission planning, but that is exactly what collaborative tools like electronic white boards are designed to do. Our results imply that team or organizational elements planning in a distributed manner will not be at a disadvantage to those planning in face-to-face sessions.

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