

COVER SHEET

The Effects of Leader Role and Task Load on Team Performance and Process in an AWACS Environment

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TOPIC: C2 Experimentation

The Effects of Leader Role and Task Load On Team Performance and Process¹

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Abstract

We manipulated two variables predicted by models of team performance to affect team processes and performance: team organization and task load. In one team organization the team leader served as a manager only, without responsibility for prosecuting hostile tracks. In the other organization the team leader served as a player-manager. Task load was established by varying the number of hostile tracks. As hypothesized, teams performed at a higher level, that is took less time to act, when task load was low than high. Counter to predictions no performance differences were found between the two team organization conditions, but as anticipated, performance differed among team members by task load. Additionally, teams in which the team leader was a manager only were more proactive and transferred more information to other teammates without requests to do so, a communication pattern that has been shown to be indicative of high-performing teams.

Introduction

A critical need exists for a solid understanding of team decision-making and the factors that influence it in order to identify interventions to improve team processes and performance (Salas, Bowers, & Cannon-Bowers, 1995). We conducted a research program to improve understanding of the functioning of high-performance military teams in the context of complex, distributed environments that require tightly coordinated performance to meet a range of shared goals. As part of this program we conducted an experiment in the AWACS domain to investigate some of these issues. Prior to the experiment we conducted a cognitive task analysis of the AWACS environment. This was performed to learn the current roles and responsibilities of the different AWACS team members and to learn enough about AWACS missions to create analog scenarios for a simulation application.

In the last few years, the team research community has produced several models of team performance that provide a frame of reference for the research issues relevant to this effort. Our research was guided by two separate yet complementary models—the Integrated Team Model (ITM; Salas, Dickinson, Converse, and Tannenbaum; 1992) and the Adaptive Team Model (ATM; Serfaty, Entin, & Johnston; 1998). Both models relate key variables relevant to the context of dynamic team resource allocation and they are supported by empirical data. In AWACS command and control, there is little consensus about the best distribution of responsibility across the weapons directors (WDs) and

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senior director (SD) in the team. One possible model is that all team members participate in command and control taskwork, monitoring tracks and supporting in-flight pilots. Another possible model defines the SD role as one of "manager" or maintainer of the global picture and divides the taskwork among the remaining members of the team. It was our intention to use the two models as guides to investigate these team organizational issues within an AWACS command and control team. To address the concern that at low levels of workload team organization may not be an issue, we manipulated workload over low and high levels. We made our systematic observations using the moderate fidelity distributed dynamic decisionmaking (DDD) simulator and specifically designed team resource allocation task scenarios. Before discussing the experiment itself we briefly review the two models and show how they were used to derive the independent variables.

The Integrated Team Model

The Integrated Team Model, portrayed in Fig. 1, was first proposed by Salas, Dickinson, Converse, and Tannenbaum (1992). The model is based on insights from several other models including the Normative Model; Time and Transition Model; Group Effectiveness Model; Team Evolution and Maturation Model; Team Performance Model; and several task-oriented models (Salas et al., 1992). The Integrated Team Model pulls together key aspects of each of these models to represent a coherent picture of the range of factors that can influence team processes and performance. In the course of our research, we have investigated the effects of theoretically motivated manipulations of several of these factors including individual and task influences, team structure and organization, and outside influences such as load, tempo, and interface design.

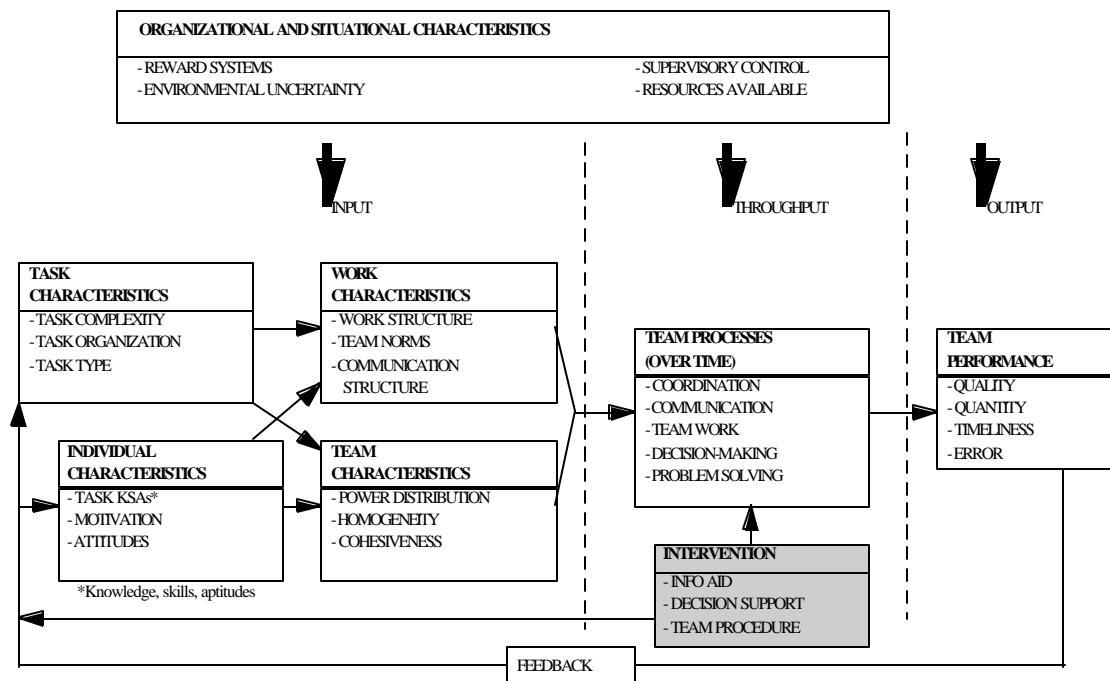


Figure 1. Integrated Model of Team Performance and Training (based on Salas, Dickinson, Converse, and Tannenbaum, 1992, with permission)

The Adaptive Team Model

A second model that is used to guide our research is called the Adaptive Team Model, illustrated in Fig 2. The Adaptive Team Model was proposed by Serfaty, Entin, & Johnston (1998), and is based on the proposition that team adaptation mechanisms can provide a key link between shared knowledge (team cognition), teamwork strategies (team behavior), and performance (team outcome). The central premise of the Adaptive Team Model is that, under conditions of increasing task demands, high-performing teams are able to adapt their: 1) decision-making strategy, 2) coordination strategy, and 3) organizational structure in order to maintain team performance at acceptable levels while keeping perceived stress (or, alternatively, subjective workload) at tolerable levels. Rather than adopting a fixed approach to teamwork that is used under all circumstances, successful teams use their knowledge of the situation and of the team to adapt their behavior to the demands of the situation. Hence, this model predicts that a critical aspect of any intervention or team training strategy is to help teach team members to be more sensitive to and aware of changes in one another's task demands (Salas and Cannon-Bowers, 1995).

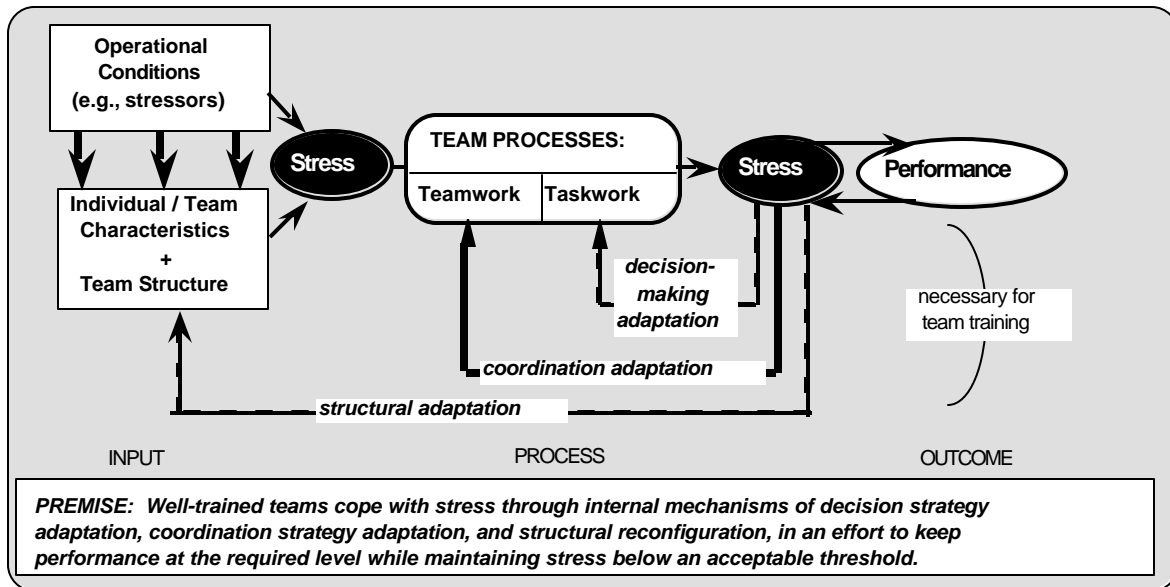


Figure 2. The Adaptive Team Model

The Adaptive Team Model suggests an important mechanism utilized by highly effective teams in the adaptation process is the development of shared situational mental models of the task environment, the task itself, and of interacting team members' tasks and abilities. These knowledge structures are used to generate expectations about how other team members will behave (McIntyre and Salas, 1995; Cannon-Bowers, Salas, and Converse, 1993; Orasanu, 1990; Serfaty, Entin, and Volpe, 1993). Moreover, there is research evidence to show that high-performing teams make use of such "shared mental models" (Cannon-Bowers, Salas, & Converse, 1993; Entin & Serfaty, 1999; Kleinman & Serfaty, 1989; McIntyre and Salas, 1995; Orasanu, 1990), particularly when timely, error-free,

and unambiguous information is at a premium, to anticipate both the developments of the situation and the needs of the other team members.

Derivation of Independent Variables from the Team Models

Team Organization

In both the Integrated Team Model and the Adaptive Team Model, team performance is hypothesized to be a function of team characteristics including *team structure* and the *distribution of responsibilities across team members*. As discussed above there is little consensus about the best distribution of responsibility across the WDs and SD in the team. Two models are under consideration: the SD as a warriors and manager and the SD as a "manager" or maintainer of the global picture. According to both guiding models, these two team organizations should produce different team performance and processes. For instance, the Adaptive Team Model predicts that, under certain conditions, teams with a managerial SD will demonstrate more adaptive performance and be able to cope with sudden changes in load distribution and demands. In the player-manager condition, where the SD is engaged in engrossing interaction with pilots and potentially maintaining a restricted view of the action, the Adaptive Team Model would predict poorer performance and greater susceptibility to performance decrements under increasing task load.

Task Load

Both the Integrated and the Adaptive Team Models suggest that organizational and situational characteristics such as the availability of resources, task pace, and task load can exert influences at all stages of team performance: input, throughput, and output. This suggests that relatively simple changes in environmental pressures (such as task load) can have impacts on performance, and that these effects might be evident in outcome and/or the processes that lead to final outcome. In our experiment, we manipulated the task management demands faced by participants by increasing the number of hostile tracks that each WD/SD team must process. Increased task load requires that each team member attend to more tracks in addition to the overhead necessary to coordinate and perform as a team. We predicted that performance would suffer as task load increases.

Method

Subjects

Fifty-two student volunteers from classes at the US Air Force Academy (USAFA) served as participants. Participants were randomly assigned to one of 13 teams. Each team participated in three trials.

Independent Variables and Experimental Design

The two team organization levels were produced by providing teams with differing instructions regarding the distribution of responsibilities and the role of the SD. In the *manager* level of team organization, the SD was given no prosecution assets and performed the role of team manager, monitoring and directing the WDs and reallocating their attention and effort when necessary. In the *player-manager* level of team

organization, the SD was given prosecution assets and participated in the same command and control activities as the other three WDs, playing a managerial role when possible.

The levels of task load were produced by varying the number of hostile tracks to be processed in a 20 minute trial. A total of eight hostile tracks appeared for the *low*, ten for the *moderate*, and twelve for the *high* task load level. To assess the effectiveness of the task load manipulation the mean Task Load Index (TLX) workload score (Hart and Staveland, 1988) was computed for each trial. As we can see in Fig. 3, the workload means increased significantly with each level of task load ($p < .05$). We concluded that the manipulation produced three conditions of increasing task load, as intended.

The two levels of team organization were completely crossed with the three levels of task load to produce a 2x3 mixed factorial with team organization manipulated as a between-subjects variable and task load as a within-subjects variable.

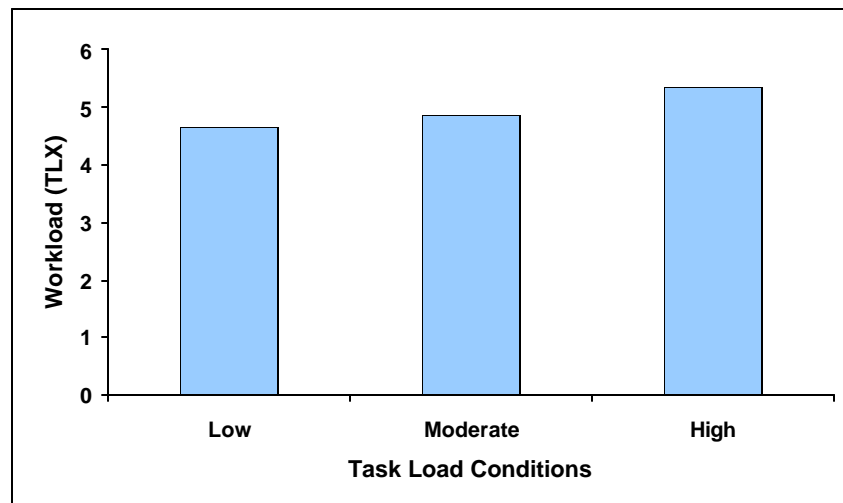


Figure 3. Self-Report Workload for the Task Load Conditions

Dependent Variables

Measures were organized into three general classes: 1) performance outcome measures that were derived from log files of the DDD simulation; 2) process measures derived from the observations of trained observers, and; 3) process and attitude assessments derived from self-report measures. Average attack latencies were derived for teams and individual team members from the log files generated by the DDD simulator. Observers equipped with hand-held computers coded the verbal communications in real time. The hand-held computers had touch sensitive screens and were equipped with specially designed software that allowed the observers to record the “from-to” of each message and the type of message. Ten different type categories were available (e.g., information request, information transfer, action request, acknowledgement). A number of different dependent measures were derived from the coded communications data (e.g., communication rate, communication rate upward to the SD, communication rate downward to the WDs, lateral communication rate among the WDs, information request

rate, information transfer rate). At the end of each trial participants completed the five-item self-report workload assessment measure, the TLX (Hart & Staveland, 1988).

Experimental Procedure

Each four-person team completed two sessions each of which lasted approximately two-hours. The first session was used to train the team to use the DDD simulation, brief them on the task they would perform, and randomly assigned them to one of the levels of team organization. Participants were given an opportunity to engage in a short practice session as a team at this time. During the second session, participants were reminded of their mission and the team organization, and then performed three trials comprising the three levels of task load. All teams completed the moderate task load level first as a practice trial. The low and high levels of task load, the two levels used in the data analyses, were counter-balanced across the teams i.e., half the teams performed the low level and half the teams performed the high level first after the moderate level.

The experiment was conducted at the USAFA. Each of four computer workstations hosted the necessary DDD software and scenarios and participants sat at one of the workstation. Participants were unable to directly view one another's computer screens. They were, however, able to communicate with one another over headsets available at each station and through display-integrated Email.

Figure 4 shows the basic task display seen by each participant in the team. Superimposed on a map background are symbols representing *tasks* (enemy aircraft, surface to air weapons bases) and *assets* (friendly aircraft, friendly bases, surveillance assets).

Participants must work together to control and coordinate available assets in an effort to protect the region from advancing enemy aircraft.

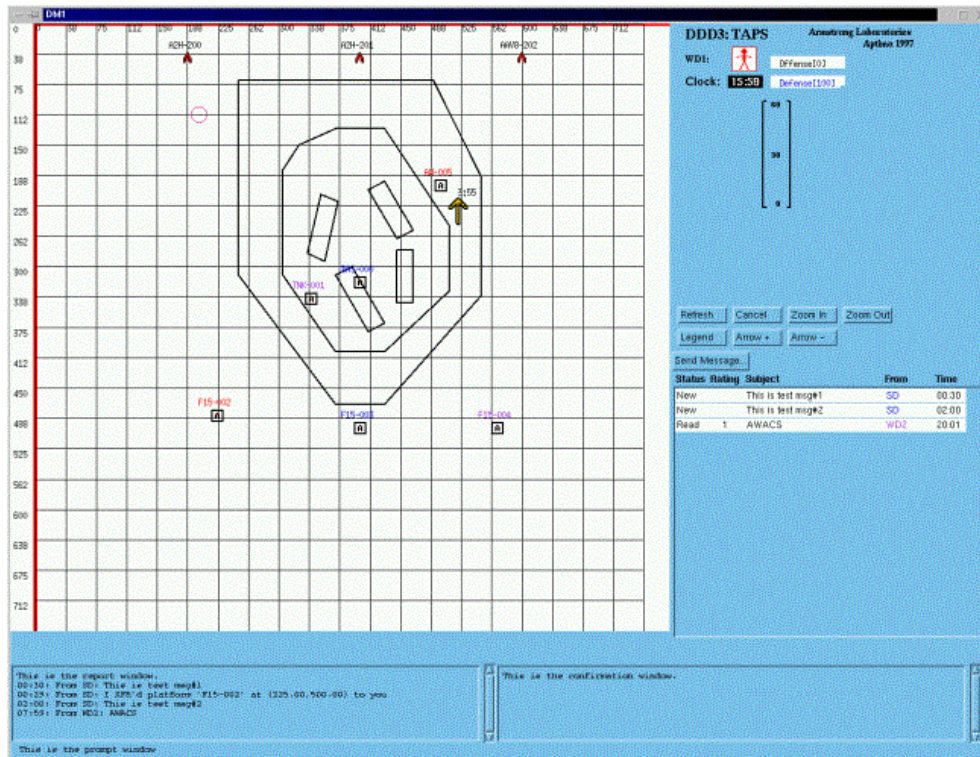


Figure 4. DDD AWACS Team Task Display

Results and Discussion

Performance Outcome

Attack latency is the time from the first appearance of a hostile track to the time it is engaged by a Blue asset. Attack latency is computed for each hostile track appearing in a trial. The times are then averaged over the number of hostile tracks to yield average attack latency. Because we do not expect the roles and taskwork to be the same for each team member, we computed the average attack latency for each team member based on the hostile tracks that each team member engaged.

From the perspectives of the Integrated Team Model and the Team Adaptation Model we predicted lower performance in the high than low task load condition. Shorter latencies are an indication of quicker responses and generally accepted as a measure of successful performance. A multivariate analysis of variance (MANOVA) showed that average attack latency was significantly lower in the low (mean = 195.5 sec.) than high (mean = 208.5 sec.) task load condition ($p < .065$). Both the Integrated Team Model and the Adaptive Team Model predict that team structure and the distribution of responsibilities across team members will impact performance. As hypothesized teams performed at a higher level (i.e., responded more quickly) under the low task load condition. There was no difference in the means for the two levels of team organization, but as anticipated, performance differed among team members ($p < .007$). As shown in Fig. 5, averaging across team organization, the SD position had the highest latency, whereas WD-3 posted the lowest latency.

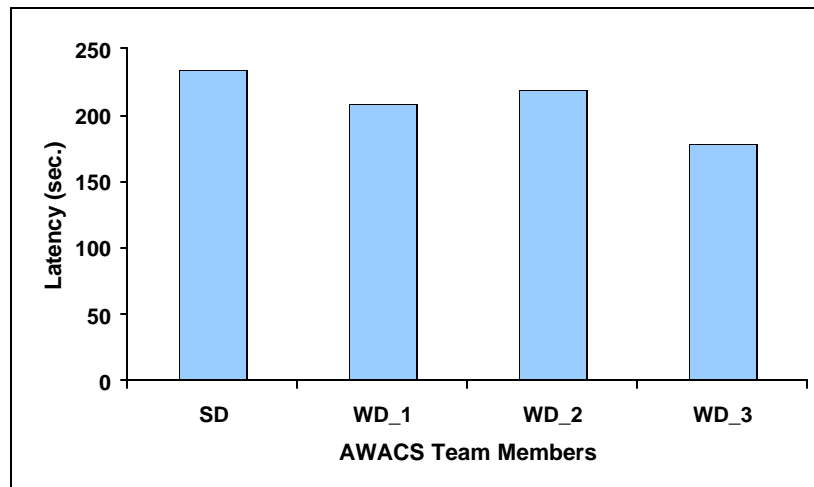


Figure 5. Average Attack Latency (seconds) for Team Members

Counter to expectation task load did not interact with team organization. The MANOVA, however, revealed that task load significantly interacted with team members ($p < .008$) and team organization interacted with team members ($p < .001$). In Fig. 6, we see that the SD and WD-2 exhibited higher performance (i.e., responded quicker) in the

low task load condition while WD-1 and WD-3 exhibited the higher performance (i.e., responded quicker), in the high task load condition. Figure 7 shows that when SDs were player-managers they responded quicker than any other team member, whereas when SDs were managers they took the longest to respond. In the manager condition SDs began with no prosecution assets, probably did not attempt prosecution until late in the scenario when it appeared that some hostile tracks were going unengaged, and had to wait for asset transfers to attack hostile tracks. All this adds up to longer response times. The WDs, by contrast, exhibited the shortest latencies when the SD was a manager versus a player-manager. With one less person processing tracks (at least initially) the WDs probably were motivated to engage tracks early and quickly.

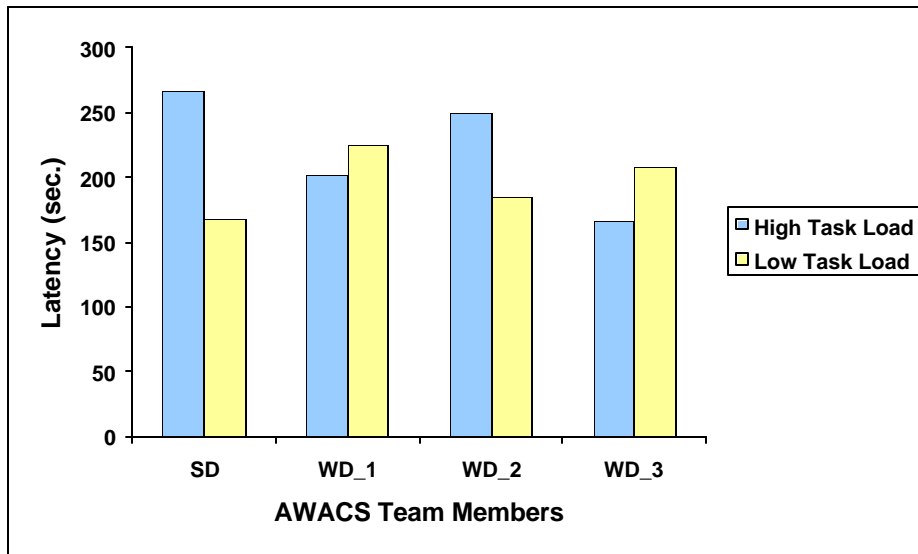


Figure 6. Average Attack Latency by Task Load and Team Members

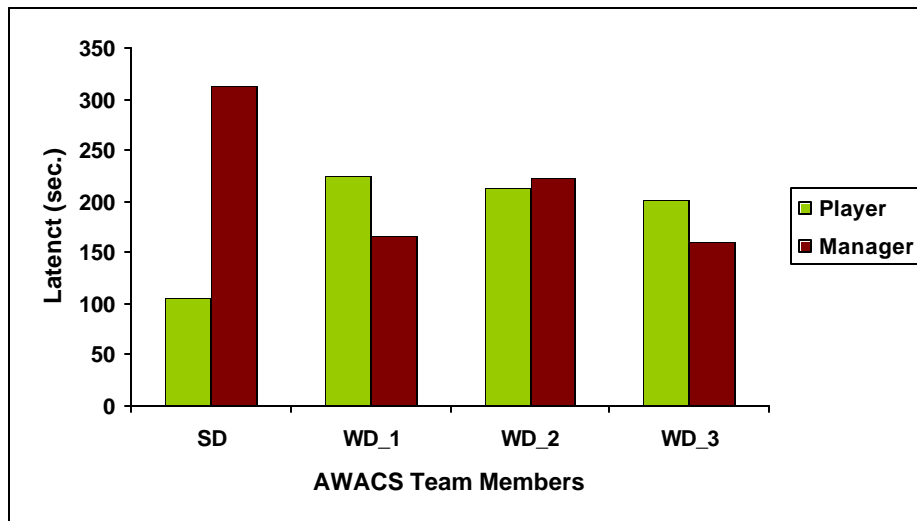


Figure 7. Average Attack Latency by Team Organization and Team Members

Looking at the pattern of results in both interactions, for SDs, it appears that task load had a negligible effect when the SDs were player-managers compared to when they were managers. The WDs were essentially compensating when the SD was a manager and was not taking an immediate active prosecution role. In this case the WDs felt compelled to act quickly. When the SD was a player-manager and was initially active in prosecuting targets the WDs did not feel as pressured to act as early or quickly.

Process Measures

We examined several process measures, key among them communications. We expected from both models that process measures should provide the underpinning rationale for performance. Where performance is high we should find positive processes contributing to performance level. We focused first on communication rate and the directional flow of messages among the team members. The mean overall communication rate in the low task load condition, 3.4 messages per minute, is significantly higher than 2.9 messages per minute observed in the high task load condition ($p < .007$). Higher communication rates can be indicative of higher coordination and information transfer rates supporting performance. Moreover, as task load increases, team members are more occupied with processing hostile tracks and have less time to communicate. The means for the two team organization conditions did not differ, nor did the interaction between team organization and task load reveal any differences.

To examine the directional flow of communications we computed three measures: upward communication rate (messages from the WDs to the SD), downward communication rate (messages from the SD to the WDs), and lateral communication rate (messages sent among the WDs). The means for these three measures by the two independent variables are displayed in Fig. 8.

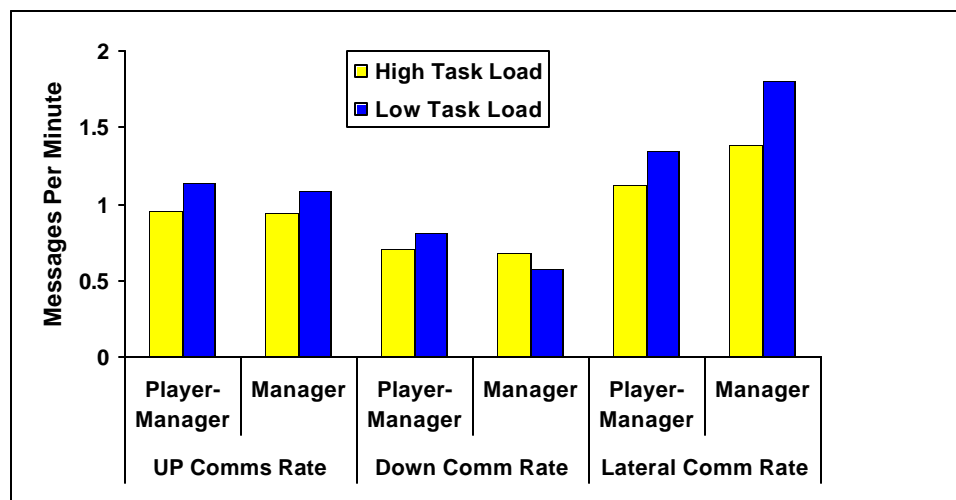


Figure 8. Upward, Downward, and Lateral Communication Rates by Task Load and Team Organization

None of the differences for upward communication rate were significant. Downward communication rate increased little, about 4 %, in the direction of the player-manager

condition when task load was high. Turning to lateral communication rate, we see that the lateral rate went up some 22 % (n.s.) in the direction of the manager condition in the high task load condition, whereas the increase was 35 % ($p < .05$), in the direction of the manager condition in the low task load condition. We suspect that when the WDs receive fewer messages, and therefore presumably less direction from their SD, they compensate by communicating more among themselves – which we assume is coordinative in nature.

To learn how the two independent variables affected the types of messages that were sent, analyses of the ten message categories were carried out. Reliable differences were found for several of the communication categories. One pair of categories that accounts for 40% of messages sent is information requests and information transfers. The average number of information requests was 10.2 messages in the low task load condition, and that is significantly higher than the 7.6 messages for the high task load condition ($p < .055$). This finding is in accordance with higher communication rate found under the low task load condition. From this result we can surmise that an important part of the increased communication rate is requests for information. However, this is only half the story. A meaningful strategy to examine information requests and information transfers is to analyze them jointly as a ratio (see Entin & Serfaty, 1999). The joint analysis is discussed next.

It is possible that under some conditions team members are more anticipatory of other teammates' needs and push information before being requested for it. Entin and Serfaty (1999) have noted that this anticipation of needs is a quality of high performing teams. They also propose the use of the anticipation ratio to investigate this characteristic of team behavior. The information anticipation ratio is computed by dividing information transfers by information requests. If members of a team are anticipating the needs of others and pushing more information than they are requesting, the anticipation ratio will be greater than 1.0. If team members send no information until requested and sometimes forget to answer a request, the anticipation ratio will be less than one. Thus, the more team members anticipate the information needs of others and push information, the larger the information anticipation ratio.

From Fig. 9, we can see that in both task load conditions team members exhibited a larger anticipation ratio when the SD is a manager than when the SD is a player-manager ($p < .05$, one tail). If, as argued by Entin and Serfaty (1999), we can assume that anticipation ratios considerably larger than one indicate high performing, adaptive teams, then we see a confirmation of the hypothesis derived from the Team Adaptation Model that teams whose SDs are managers will be more adaptive than teams whose SDs are player-managers.

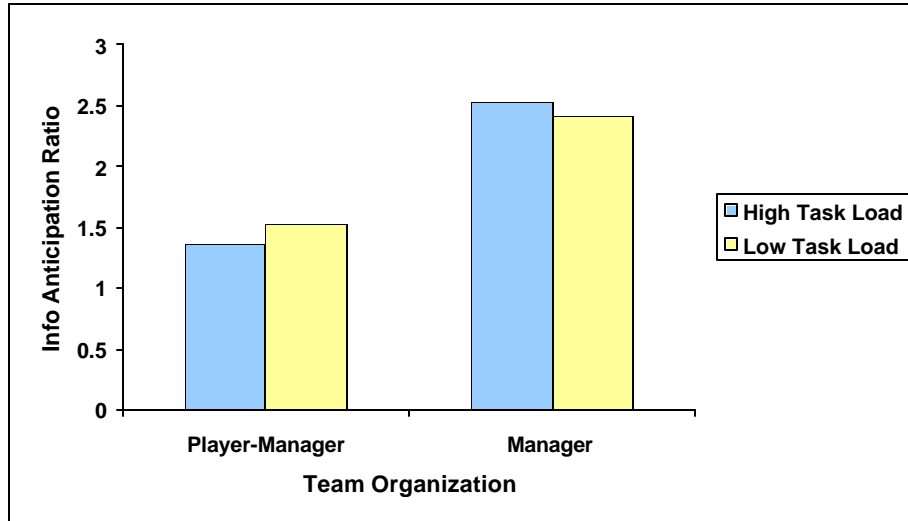


Figure 9. Information Anticipation Ratio by Task Load and Team Organization

Another set of important categories includes resource utilization requests and resources used to perform an action. As depicted in Fig. 10, more requests for resource utilization were made under the high than low task load condition ($p < .068$) and more requests for resource utilization occurred when the SD was a manager than a player-manager ($p < .085$). Further inspection of Fig. 10 reveals that the difference in requests between the manager condition and the player-manager condition is three times larger in the high task load condition than in the low task load condition. Being able to request that a particular team member use a specific asset (against a hostile track) implies that team members have accurate mental models of each other and the situation, another indication of an adaptive team, providing further confirmation for the Adaptive Team Model. Fig. 11 shows that when task load is low and there is enough time, adaptive teams (i.e., those whose SDs are managers) push messages to one another informing them what resources they have or will use against a hostile track more than less adaptive teams (those whose SDs are player-managers) ($p < .035$). Analysis of the message categories also showed, in accordance with the higher communication rate, that there were significantly more acknowledgements sent in the low than the high task load condition ($p < .005$).

Summary and Conclusions

Two models were used to guide the experiment design and the interpretation of results, the Integrated Team Model (Salas et al., 1992) and the Adaptive Team Model (Serfaty et al., 1998). In accordance with predictions from the two models, teams took less time (shorter latencies) to act when task load was low than when it was high. Having fewer hostile tracks to deal with allowed teams to respond more quickly to the ones that did appear. We hypothesized, but could not confirm with the latency scores, an advantage of the managers over the player-managers at the higher (or lower) workload levels. Counter to expectation, task load and team structure did not interact. We did note a large amount of variance in the latency scores so perhaps some intervening noise variable obscured the relationship between team structure and task load.

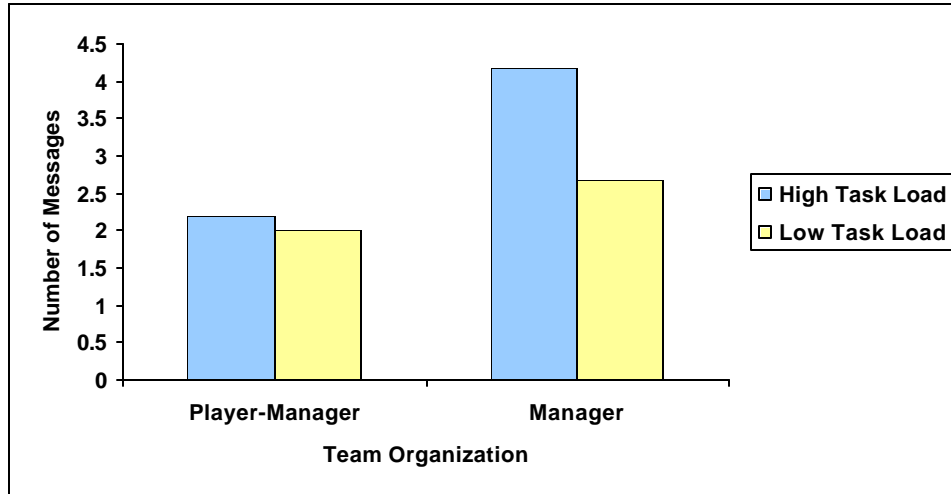


Figure 10. Number of Resource Utilization Requests by Task Load and Team Organization

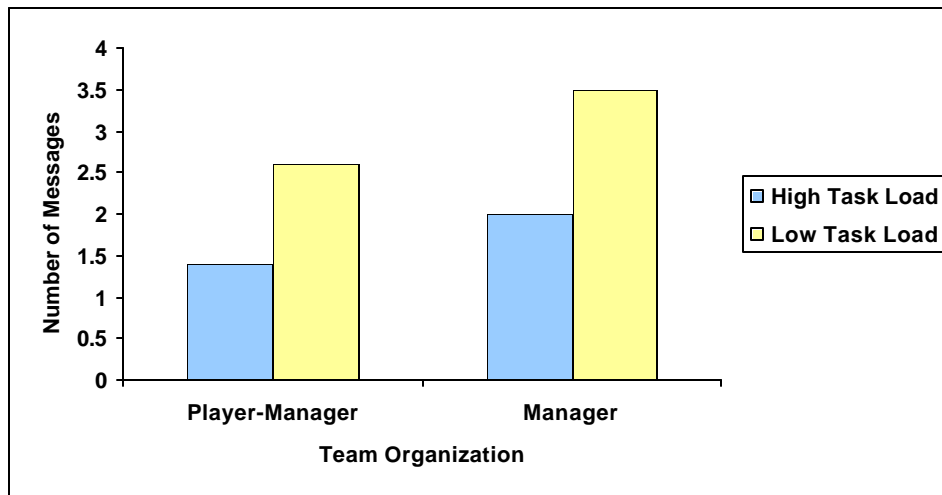


Figure 11. Number of Resource Usage Messages by Task Load and Team Organization

We did observe that both team structure and task load interacted with team member, indicating that team members reacted differently to task load and team organization. We noted that many SD managers could not resist the temptation to participate and ultimately chose to obtain assets and prosecute hostile tracks, but this occurred late in the scenario. On the other hand, because they assumed a role as player at the *outset* of the scenario, SD player-managers acted more quickly than SD managers in prosecuting targets. In fact, SD player-managers had the shortest latency of any team member in both the low and the high task load conditions. Perhaps as a way of compensating for the smaller number of team members involved in prosecuting targets, team members of SD managers acted more quickly than the team members of SD player-managers.

In terms of process measures, the analysis of the information anticipation ratio appeared most useful in discriminating the two team organization conditions. Recall that prior research (cf., Entin and Serfaty, 1999) indicates that high performing teams exhibit large information anticipation ratios. Teams whose SDs were managers were more proactive and transferred more information to other teammates without requests to do so, thus exhibiting larger information anticipation ratios than teams whose SDs were player-managers. Entin and Serfaty (1999) also note that for team members to be able to preempt the needs of their fellow team members, they must have accurate mental models of others and the situation. Based on communication process results, we concluded that the SD managers appeared to monitor the team's workload and attempted to balance the load by participating themselves.

The collection of outcomes may indicate that teams with SD managers actually performed at a higher level than teams with SD player-managers, but we could not verify this using the performance measures derived from the DDD simulator because teams prosecuted all the hostile targets in the high as well as the low task load conditions. Had more sensitive performance measures been available the differences between the two conditions might have been observable.

The experiment results show that our approach, utilizing a controllable yet behaviorally rich medium-fidelity simulation, coupled with theory-grounded manipulations, is an appropriate way to investigate potential team training interventions. The results of our research advance to some limited extent the state of knowledge in areas including team performance, simulation-based research and performance assessment, organizational design for command and control, and training interventions for AWACS and similar command and control environments.

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