# Communications and Coordination Across Low and High Fidelity Simulation Environments[1]

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## Abstract

Most research conducted for the Adaptive Architectures for Command and Control (A2C2) project has been carried out using a capable, but low fidelity simulation, the Distributed Dynamic Decision making III (DDD-III). A goal of the A2C2 project has been to transition some of the research to higher fidelity simulations. To that end a partial replication of a DDD-III-based experiment contrasting optimized and non-optimized architectures was carried out using a high fidelity training simulation, the Marine Air Ground Task Force (MAGTIF) Tactical Warfare Simulation (MTWS). The key finding that a smaller team using a non-traditional, optimized architecture can perform as well as a larger team using a traditional, non-optimized architecture was replicated in the MTWS environment. Additional findings indicated that the MTWS simulation was more complex and less determined than the DDD-III. We conclude that findings obtained using the low fidelity DDD-III simulation will also be obtained when a high fidelity simulation like MTWS is used.

## 1 Introduction

It is hard to underestimate the importance of communication to team performance. Communication is more than an exchange of information. It is a means by which teams coordinate resources and activities (Entin and Serfaty, 1999), construct and maintain shared mental models (Orasanu, 1990), and establish and maintain situational awareness (Prince and Salas, 1993). Of the many team process measures we assess as part of the experimental effort of the A2C2 project, communication is one of the most important. It is through the analysis of verbal communication that we assess the impact of various organizational structures on coordination, the validity of shared mental models, and the patterns of information sharing.

A component of the A2C2 project is to investigate whether findings obtained in a low fidelity simulation environment can be replicated in a high fidelity simulation environment. Heretofore, most experimental work within the A2C2 project has been performed employing the low fidelity DDD-III research simulator (Kleinman, Young, and Higgins, 1996). As a research tool the DDD has many virtues. The DDD has been used extensively since 1989 in research involving “open ocean” naval team decision-making. It has served as the vehicle by which teams of subjects interact in a dynamically

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evolving tactical scenario. The DDD-III creates a reasonable Joint environment within a computer simulation, yet allows easy manipulation of key structural variables, avoids the need for technical domain experts in subjects, and eases scenario design, data collection, and retrieval (Kleinman et al., 1996). The DDD allows for a high degree of experimental control and provides on-line data collection of subjects' interactions in a log file that can be used to develop performance variables. To address the question of whether results obtained with the DDD would be similar to results from a high fidelity training simulator, the scenario and forces used with a DDD experiment were adapted to the MTWS environment. MTWS was constructed by its marine architects to provide participants with a realistic experience in terms of displays, missions planning, issuing commands, and obtaining feedback.

## 2 The DDD-III Based Simulation Experiment

In an experiment performed with the DDD simulator, Entin (1999) observed teams performing a mission under three different organizational structures: a six-person non-traditional structure derived from the A2C2 modeling effort (Levchuk, Pattipati, and Kleinman, 1998; Levchuk et al., 1999) that was optimized for the mission and to reduce inter-nodal coordination; a six-person traditional non-optimized structure derived by staff and students at the Naval Postgraduate School (NPS) employing current doctrine; and a four-person non-traditional optimized structure also derived from the A2C2 modeling effort. In accordance with the findings of Entin, Serfaty, and Kerrigan. (1998), the researchers hypothesized that if teams were given sufficient practice with each architecture to make them equally familiar, performance under a model derived, non-traditional optimized architecture would prove superior to performance under a traditional non-optimized architecture. They further hypothesized that when the architectures were on equal footing regarding familiarization, a model derived optimized architecture would allow a smaller team to accomplish the same mission as a larger team performing the mission with a non-optimized architecture (Entin, 1999).

Sixty active duty military officers from all services attending NPS (Monterey, CA) were randomly assigned to one of ten six-person teams. Each team performed two C2 scenarios under two of the three architectures. In addition to overall performance outcome, the researchers, collected process measures (e.g., teamwork, communications, situation awareness), simulator derived performance measures (e.g., task accuracies), and self-report survey data.

Results from observer-based and simulator-based performance outcome measures indicated that when teams had sufficient practice with a six-person model derived non-traditional optimized organizational structure, they performed at a higher level than when using a traditional six-person non-optimized organizational structure. Moreover, performance under a four-person model derived non-traditional optimized structure was equal to that of the six-person traditional non-optimized structure despite the 33% reduction in manpower. Optimization of the four-person organizational structure apparently made up for the decrease in personnel.

Process measure results corroborated the performance findings. Team communications offer an excellent window into team behaviors and processes. Some measures compliment the performance findings, whereas others imply a link between architecture and team processing. The information anticipation ratio, formed by dividing information transfers by information requests, assesses how well team members anticipate other team members' information needs and push information to them before being asked for it (Entin., Serfaty, and Deckert, 1994). Ratios above one imply team members are pushing more information to others than they have received requests for. The pattern of results indicates that information anticipation was highest with the optimized six-person architecture and lowest with the non-optimized six-person architecture. For team members to successfully anticipate the information needs of others, they must have an accurate mental model of the situation and other team members (Entin et al., 1994). The information anticipation results indicate that the model derived non-traditional optimized architecture fostered the development of better mental models of the situation and other team members.

## 3 The MTWS Based Simulation Experiment

The well-articulated nature of the mission, scenarios, and architectures used in the DDD-based experiment (Entin, 1999) made them good candidates for transition to a higher fidelity simulation environment (Wollenbecker, 1999). The watershed nature of this transition only allowed for a partial replication of the DDD experiment on the MTWS simulator. Wollenbecker (1999) provides a detailed description of the rationale for, conduct of, and results from the MTWS-based experiment. We present a brief description of the experiment.

Twenty NPS active duty officers from all services were organized first into six-person and then into four-person teams. The six-person architecture was the traditional non-optimized organizational structure employed by Entin (1999). The four-person architecture was the model derived non-traditional optimized organizational structure, also from Entin (1999). With minor alterations performance, teamwork, self-workload, others' workload, and team situation awareness were assessed in the same way as in Entin (1999). As in Entin (1999), the real-time coding of communications among team members was accomplished by two observers using hand-held 3Com Palm III computers. A primary goal of the experiment was to test the hypothesis that team performance under the optimized four-person architecture would be equivalent to team performance under the traditional non-optimized six-person architecture. Such a finding would replicate the results found in Entin (1999).

## 4 Results Comparing the Two Simulations

The performance results comparing the six-person traditional non-optimized to the four-person model derived, non-traditional optimized organizational structure replicated the earlier DDD based findings. Performance levels were the same for the two structures despite the 33 % difference in manpower. Given that the results of the MTWS based simulation experiment replicated the findings found with the DDD based simulation experiment, our next task was to compare and contrast the underlying processes in the two simulators.

In the highly abstract world of the DDD simulator, the mappings of resources, tasks, and roles are much more specific than in the high fidelity world of MTWS, suggesting that in the more complex MTWS environment participants will have a lower understanding of the situation and what others are doing at any given time in the scenario. We therefore hypothesized that communication rates would be higher and indices of shared situational understanding and shared mental models (e.g., what others are doing) would be lower in the MWTS environment.

The process of capturing and assessing oral communication was the same in the two studies. A hand-held 3Com Palm III computer equipped with a touch sensitive screen and special software displayed a recording matrix. The rows of the matrix represented categories for message type and content while the columns represented “from – to” information. Two trained coders, who were connected to the communication net via earphones, coded each communication between team members by touching the appropriate cell of the matrix with a stylus. The software automatically recorded the cell number and the time (i.e., number of seconds from the start of the simulation) for each entry. Thus, a time stamped coding of communications within the team was obtained.

The dependent variables were obtained by summing across appropriate rows and/or columns of the matrix. Analyses depicted in Fig. 1 show that the communication rate, the communication rate per team member, and the action request rate were higher in the MTWS than DDD experiment. As hypothesized, the more complex environment required a higher communication and a higher request for action rate to prosecute tasks and perform the mission. We computed the information anticipation ratio to gage whether team members’ needs were being met without them having to ask for it. Anticipation ratios larger than 1.0 also implies that team members must possess accurate shared mental models to effectively preempt the needs of fellow teammates (Entin and Serfaty, 1999). The information anticipation rate, shown in Fig. 2, was higher in the DDD than in the MTWS simulation. Also, as predicted, team members in the in the DDD simulation were able to construct and maintain more accurate shared mental models, allowing them to preempt the needs of other team members.

We examined two other variables that gage perceived workload and the congruence among team members’ mental models. Team members in the DDD based study reported higher perceived workload than team members in the MTWS based study (means of 12.8 and 7.7, respectively). At first this result appeared contradictory to the previous finding. However, when we consider the tasks each team member must complete the results appear more consistent. With the DDD, team members must perform their tasks to accomplish the mission and enter all the simulator commands to accomplish this. The complex environment of MTWS required a knowledgeable operator to effect the commands given by the decision maker. Thus, the decision makers in the MTWS simulation environment only had to focus on the mission and not the simulator overhead, as did the DDD users.

If team members possess good situation awareness they have an accurate model of the situation and the other team members. Analysis showed that situation awareness scores for the teams in each simulator environment were about the same. This would indicate that decision makers in each simulation environment are obtaining about the same amount of information to maintain about the same level of awareness, despite the fact that overage message rate was higher in the MTWS environment.

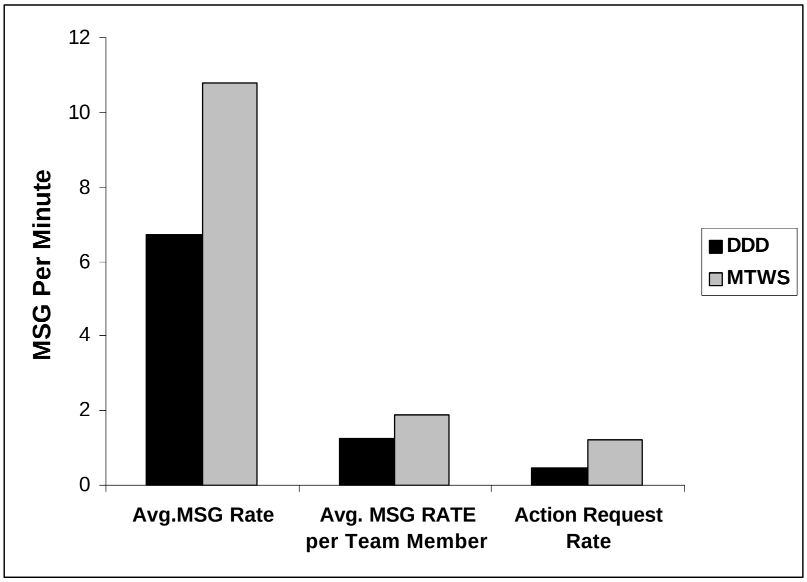


Figure 1. Communication and Action Request Rates in the DDD-III and MTWS Environments

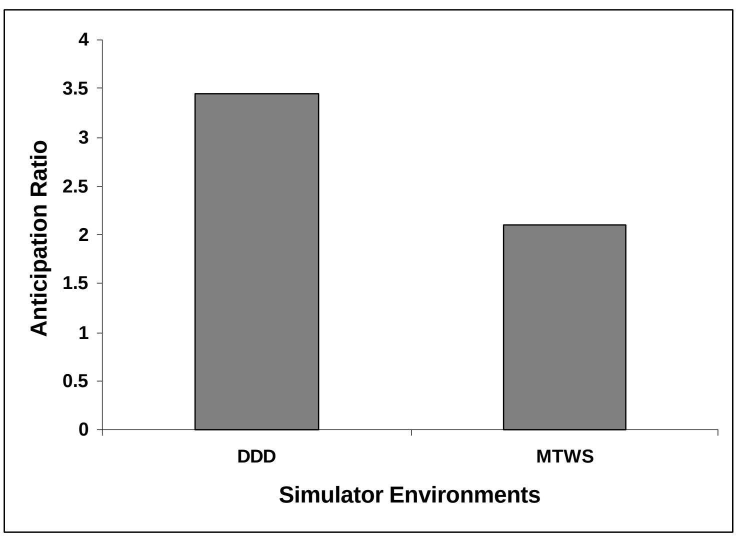


Figure 2. Information Anticipation Ratios in the DDD-III and MWTS Environments

## 5. Conclusions

An experimental design and scenario were successfully transitioned from a low fidelity to a high fidelity simulation environment. The finding obtained under the low fidelity simulation that smaller teams using an optimized architecture can perform as well as larger teams using a non-optimized architecture was replicated using the high fidelity simulation. Analyses of communication and other underlying processes revealed some difference between the two simulation environments. The more complex and less determined environment of MTWS imposed a higher coordination overhead than the DDD. However, in the MTWS environment, where decision makers could focus on performing the mission and not worry about operating the simulation, they reported lower perceived workload. The situation awareness picture was less clear. On the one hand, decision makers attained higher anticipation ratios with the DDD, indicating better awareness in the more abstract and determined DDD environment. On the other hand, an instrument specifically designed to assess situation awareness revealed about the same level of awareness in both simulations. The inconsistency between these two results suggests that we may have assessed two different aspects of situation awareness. Only further research will resolve the issue.

The MTWS study was a small, initial foray into comparing low and high fidelity simulation. To truly compare whether low and high fidelity simulation environments produce similar results, transitions of complete experimental designs and through analyses of performance and process variables are necessary.

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