OPTIMIZED COMMAND AND CONTROL ARCHITECTURES FOR IMPROVED PROCESS AND PERFORMANCE[1]

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Abstract

Evidence in a recent study contrasting team performance in traditional unoptimized architectures to performance in non-traditional optimized architectures showed higher performance in the traditional unoptimized architectures. This was the case despite the fact that the optimization process matched the architecture to the mission and reduced internodal coordination. The experimenters surmised that unfamiliarity with the non-traditional optimized architectures was an important reason for the lower performance in the optimized architectures. The present experiment was conducted to improve upon the design used in the previous experiment so that a valid comparison could be made between a traditional non-optimized architecture and a non-traditional optimized one. As expected, once teams were afforded sufficient training with the non-traditional optimized architecture, they performed higher with it than with a traditional unoptimized architecture. The results provide support for a simple model linking architecture type through team processes to performance.

1 Introduction

Command and Control (C2) organizations are forced to adapt when confronted with unexpected events and tactical surprises. Entin, Serfaty, and Kerrigan (1998) note that effective organizations are able to alter their strategies or, if necessary, alter their C2 architecture to cope with unexpected changes and perform the mission. It is further surmised that some architectural configurations may be more conducive to adaptation and change than others. We hold to a simple model: the C2 architecture or organizational structure impacts team processes and team processes affect team performance. If the C2 architecture provides a flexible and conducive environment such that team processes are facilitated then the team processes will foster high team performance. Conversely, if the C2 architecture does not support team processes, for example by constricting or inhibiting them, then team processes will be degraded and result in low team performance. One research issue that has come under scrutiny is whether C2 architectures can be designed, for example through the use of optimization principles, to facilitate team processes and hence facilitate high team performance.

In a recent study (Entin et al., 1998) six-person teams performed a mission using a traditional C2 architecture to familiarize them with the architecture and mission. Each team was then required to perform two other similar missions, one using the initial traditional C2 architecture, but with 30% less resources, and another using one of two non-traditional, but optimized C2 architectures. One of the non-traditional architectures was optimized for the mission, for loss of resources, and

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14. ABSTRACT
Evidence in a recent study contrasting team performance in traditional unoptimized architectures to performance in non-traditional optimized architectures showed higher performance in the traditional unoptimized architectures. This was the case despite the fact that the optimization process matched the architecture to the mission and reduced internodal coordination. The experimenters surmised that unfamiliarity with the non-traditional optimized architectures was an important reason for the lower performance in the optimized architectures. The present experiment was conducted to improve upon the design used in the previous experiment so that a valid comparison could be made between a traditional non-optimized architecture and a nontraditional optimized one. As expected, once teams were afforded sufficient training with the non-traditional optimized architecture, they performed higher with it than with a traditional unoptimized architecture. The results provide support for a simple model linking architecture type through team processes to performance.

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to reduce internode (inter-team member) coordination. Due to the optimization it was felt that only a four-person team would be needed to perform the mission. The other architecture was similar to the traditional architecture, but partially optimized for the mission and loss of resources. Because of the partial optimization it was felt that only a five-person team would be required to perform the mission.

Entin et al. (1998) expected process and performance outcome scores to be higher in one of the two optimized architectures. They expected this even though the two optimized architectures would be non-traditional and hence less familiar to the teams than the traditional non-optimized architecture, and even though the size of the team would be reduced. They argued that the optimized architectures' milieus would be so conducive to efficient performance of the mission tasks that problems such as initial unfamiliarity with the architecture and a smaller team would be overcome. The findings, however, did not confirm these expectations. The researchers had apparently overestimated the benefit of optimization and underestimated the effects of team size and familiarity with the architecture. The performance outcome was highest in the traditional non-optimized architecture followed closely by the partially optimized architecture and lowest in the non-traditional optimized architecture. Patterns for process measures such as teamwork and workload were consistent with the performance measures.

Entin et al. (1998) speculated that conditions under the non-optimized traditional architecture were better known and understood than conditions in the non-traditional architectures, and that is why process and performance outcome measures were higher under the non-optimized traditional architecture. However, the optimization of the non-traditional architectures had also confounded team size with architecture type precluding a clear attribution of the findings.

In accordance with Entin et al. (1998), we surmised that unfamiliarity with the non-traditional C2 architectures precluded teams from benefiting from the optimization. The current experiment was conducted to examine the effects of familiarity with an architecture on performance under that architecture and to address the team-size confounding problem. We hypothesized that if teams were given sufficient practice with each architecture to make them equally familiar, the non-traditional optimized architectures would prove superior to the traditional non-optimized architecture. We further hypothesized that once the architectures were on equal footing regarding familiarization, an optimized architecture would allow a smaller team to accomplish the same mission as a larger team performing the mission with a non-optimized architecture.

2 METHOD

2.1 Participants

Sixty military officers attending the Naval Postgraduate School, Monterey, CA, were randomly assigned to ten teams.

2.2 Scenario and Mission

The C2 scenarios and missions performed by the ten teams were adapted from the North African "insertion from the sea" scenario used in Entin et al. (1998). The primary mission tasks include demining and taking two beaches, taking and holding a hill overlooking one of the beaches, identifying and destroying the correct bridge to prevent enemy forces from reinforcing enemy troops near the beach heads, taking and holding an air field, and taking and holding a sea port. In addition to the main mission tasks the team must contend with a number of additional tasks that arise at unexpected times during the scenario trial (e.g., suppressing enemy artillery, destroying FROG missile launchers, destroying enemy aircraft, destroying enemy armor). As in the previous experiments, the scenarios were hosted by the DDD-III simulator (Kleinman et al., 1996). The DDD-III is a distributed client-server simulation that provides a flexible framework in which to study team decision making and performance in complex situations.

2.3 Independent Variables

Three C2 architecture types were used: A0-6, a six-person traditional non-optimized, similar to the A0 architecture used in Entin et al. (1998); A1-6, a six-person non-traditional optimized, developed for this experiment; and A1-4, a four-person non-traditional optimized, similar to the A1 architecture used in Entin et al. (1998). Each team was randomly assigned to perform missions using two of the three architectures.

2.4 Dependent Variables

Performance outcome and teamwork skills were assessed in a manner quite similar to that employed by Entin et al. (1998). Two trained observers with military experience were present at each trial to independently assess both performance and teamwork skills using specially designed evaluation instruments (Entin et al., 1998; Entin et al., 1997; Entin et al., 1994). The performance instrument was comprised of ten behaviorally-anchored scales evaluating performance quality of the mission tasks. The teamwork instrument was comprised of seven behaviorally-anchored scales that assessed six dimensions of teamwork: team orientation, communication, monitoring, feedback, back-up, and coordination behaviors. Reliability of both instruments is high (Entin et al., 1998; Entin et al., 1997). The ratings from the two observers were compared, any large deviations were adjudicated and then the ratings from the two observers were averaged to form the performance outcome and teamwork skills measures.

The DDD-III simulator calculates and reports to the participants at the end of each trial two performance measures. "Mission" is an assessment of the percentage of mission tasks completed where each task is weighted by the percent of resource accuracy used to perform the task. "Strength" is an attrition based measure. Every time the enemy is able to afflict some damage to a team's forces, the loss is deducted from the team's overall force strength. The percentage of overall force strength remaining at the end of the trial is the strength score.

As in previous studies (Entin et al., 1998; Entin et al., 1997; Entin et al., 1994) two trained and experienced observers coded in real time all the communications occurring among team members. One observer focused on the communications uttered by half the participants while the other observer coded the utterances of the other half. In this experiment, however, the recording medium used by observers was changed substantially. The pencil and paper recording matrices were replaced with hand-held 3Com Pilot III computers. Equipped with software specifically designed for the experiment, the touch sensitive screen of each Pilot displayed the recording matrix. The matrix displayed on the screen was the same as the paper matrix used Entin et al. (1998). The two trained observers, who were connected to the communication net via earphones, coded the communications among the team members by touching the appropriate cell of the matrix with a stylus. The software recorded the cell number and the time (i.e., number of seconds from the start of the simulation). Thus, a time stamped coding of communication within the team was obtained.

2.5 Design and Procedure

The experiment was conducted in two sessions. During the first three-hour session a team engaged in two 45-minute practice trials using the architecture scheduled for the data collection trial and then completed the 45-minute data collection trial. The inclusion of two pre-experiment practice trials permitted teams to become familiar with the architecture they would be using in that experiment trial. This process was repeated again for the other architecture the team was assigned in a second three-hour session that took place one to five days later. Following the last data collection trial, each team engaged in an after-action review. The data collection trials and the after-action reviews were videotaped.

3 Results and Discussion

3.1 Performance Results

Both simulator measures showed the same pattern of results, however the strength attrition score proved more sensitive and is the simulator based assessment used in this experiment. From the observer-based performance outcome measure depicted in Fig. 1 and the simulator-based performance measure (strength attrition score) shown in Fig. 2 we can see that teams performed significantly higher ($ps < .05$) under the A1-6, non-traditional optimized architecture than under the other architectures. We can further see that when familiarity with the various architectures is equalized, optimization prevails over the traditional architecture as well as team size, i.e., teams performing with the A0-6, the six-person non-optimized architecture, performed below the two optimized architectures.

Multivariate and univariate analyses of the items comprising the performance measure show that performance on three tasks– destroy the bridge, destroy the FROG launchers, and seize the airfield/seaport–were most responsible for the difference in performance outcome between the A0-6 traditional non-optimized architecture and the A1-6 non-traditional optimized architecture. When the ten task items were regressed on average overall performance outcome, performance on the tasks destroying the FROG launchers, destroying the tanks, and taking the airfield/seaport tasks accounted for 93 % of the variance in predicting average overall performance outcome. Two tasks emerge in both these analyses: destroying the FROG launchers and taking the airfield/seaport. Interestingly a team's performance on a task that occurs unexpectedly, destroying the FROG launchers, discriminates between the A0-6 traditional non-optimized and the A1-6 non-traditional optimized architectures, as well as predicts average overall performance outcome. The other common task to both analyses is taking the airfield/seaport, a main mission task and the primary objective of the mission.

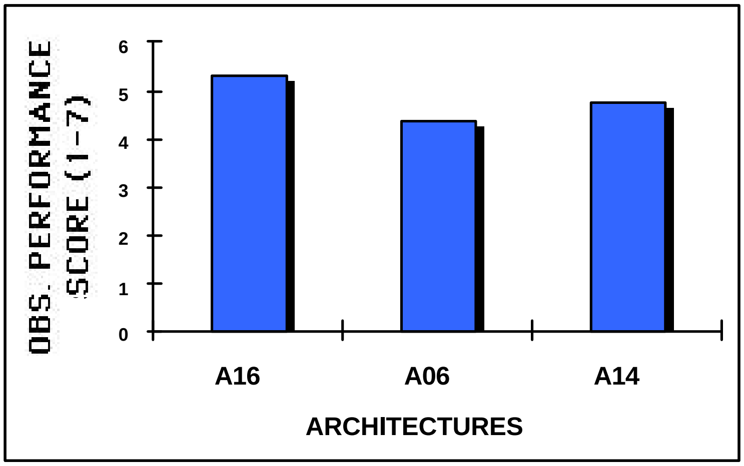

Figure 1. Observer Based Performance Scores for the Three Architectures

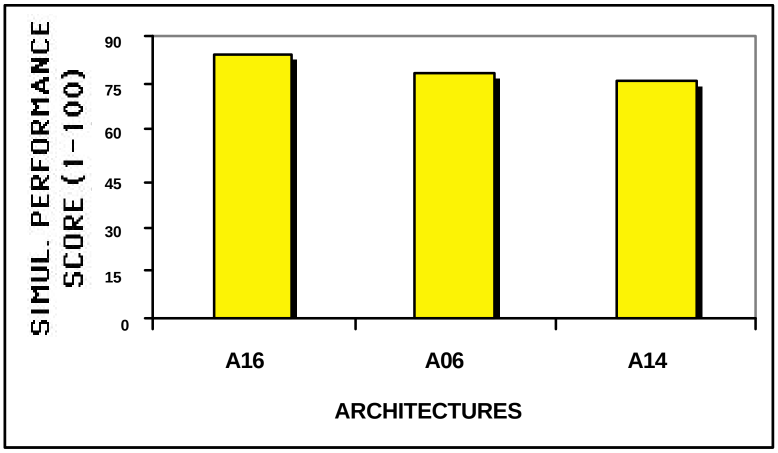

Figure 2. Simulator Based Performance Scores for the Three Architectures

3.2 Team Process Measures

Results from the observer-based teamwork measures shown in Fig. 3 corroborate the performance findings. Teamwork scores were highest when teams used the A1-6, the non-traditional optimized architecture, and lowest when the A0-6, non-optimized architecture was used (ps < .02). Four-node teams performing with the A1-4 architecture also exhibited higher teamwork scores than the six-node teams performing with the A0-6 architectures (ps < .05). Analysis of the items making up the teamwork instrument showed that two teamwork skills, monitoring and coordination behavior, were particularly salient in discriminating between the optimized and non-optimized architectures as well as in predicting the overall teamwork score. In the latter analysis, monitoring and coordination behavior accounted for 93% of the variance with the overall teamwork score.

Another important source of team process measures is team communications. Several measures derived from the communication either support the performance findings or verify a link between architecture and the process measures. The information anticipation ratio assesses how well team members anticipate other team members' information needs and push information to them before being asked for it. The pattern of results depicted in Fig. 4 indicates that the information anticipation was highest with the A1–6 architecture and lowest with the A0-6 architecture (ps < .05). 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. So in essence the information anticipation results indicate that the non-traditional optimized architectures foster the development of better mental models of the situation and other team members.

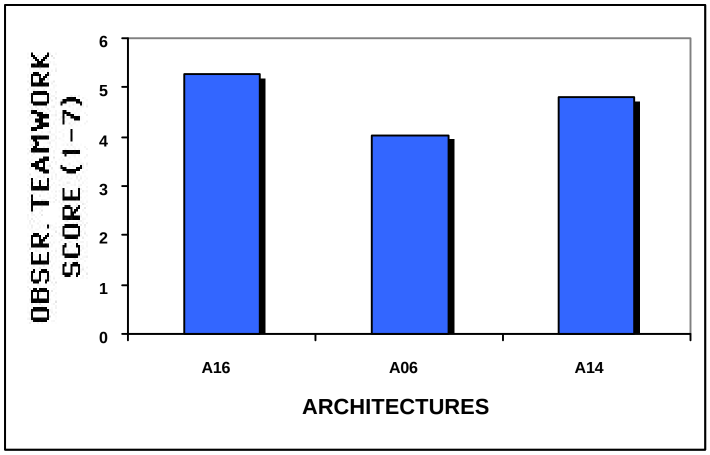

Figure 3. Observer Based Teamwork Scores for the Three Architectures

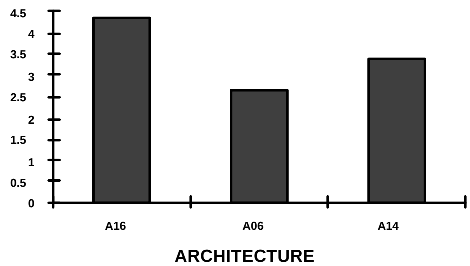

Figure 4. Information Anticipation Ratio for the Three Architectures

Analysis of the total communications rate for teams reveals that the communication rate under the A0-6 architecture was significantly higher (ps < .05, one-tail) than in the optimized architectures. Further analyses also showed that the coordination rate and the request for resource utilization were significantly higher with the A0-6 architecture than with the two optimized architectures (ps < .02). The significance of these findings can be appreciated when one considers that a goal of the optimization of the A1-6 and A1-4 architectures was to reduce internodal communication and coordination. It appears that the optimization process achieved its goal.

4 Conclusions

This experiment was conducted to improve upon the design used in the experiment described in Entin et al.(1998) so that a valid comparison could be made between a traditional non-optimized architecture and non-traditional ones optimized to accommodate the mission. Prior experimental evidence indicated that teams tend to perform highest using organizational structures they are familiar with as opposed to organizational structures that are unfamiliar, even if the unfamiliar structures are better suited to the mission. To reap the benefits of the better architecture, teams must train with and come to understand the new architecture. Findings from the prior and current experiments clearly support the necessity of practicing with an unfamiliar organizational structure. In Entin et al.(1998) the traditional A0-6 architecture fostered superior performance over the non-traditional architecture optimized for the mission tasks. When teams were afforded time to train with the unfamiliar non-traditional optimized architectures the superiority of these architectures to perform the mission surfaced and teams using them perform significantly higher than teams using the traditional (non-optimized) architecture.

To provide an explanatory mechanism for performance outcome we postulated that team processes underlay the team's performance, and that organizational structure affects team processes. Organizational structures that support important team processes give rise to high levels of team performance. When organizational structure is not supportive of effective team processes or is counter-productive to effective team processes, team performance suffers. For each of the team processes assessed–teamwork skills, workload, organizational awareness, and communications–the pattern of results always mirrored the performance outcome results. We submit that superior team processes were the foundation for high team performance. Moreover, evidence from several of the communication process measures indicate that the optimization goals of the modeling effort were achieved. The modeling effort strove to reduce internodal coordination within the optimized architectures. The findings indicate that communications, coordination, and resource request utilization were significantly lower in the optimized than non-optimized architectures. Not only were the modelers successful in constructing the desired architectures, but architecture type differentially affected team processes, as hypothesized.

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