Cover Sheet

Test Environment for FORCEnet Concepts

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Abstract

The United States Navy is undergoing a rapid transformation in the operations it conducts – the types of enemies it faces, the resources it has to draw upon, the capabilities it can deliver, the manner in which it coordinates with other branches of the armed services, and the organizational structures it uses to bring those new resources and capabilities to bear against a new generation of enemies. To accommodate this rapid transformation, a revolution has been occurring that began with the development of the concept of "network-centric warfare" (NCW). NCW promises to deliver unprecedented operational tempo and situational awareness through networked connectivity. For the Navy, the NCW concept has evolved into the definition of FORCEnet as a future organizing principle. Given this rapid transformation, several questions emerge regarding how best to realize the FORCEnet vision. These questions involve issues such as organizational design, information flow, information filtering, and display technologies. Accordingly, in this report, we describe an effort to develop an integrated testbed to explore FORCEnet concepts and technologies. The testbed is unique in that it serves to unite research on novel FORCEnet architectures with research designed to develop innovative information displays to support network-centric operations. Our intent in this report is to briefly describe this testbed, which will enable future experimentation and validation of emerging concepts.

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Introduction

The United States Navy is undergoing a rapid transformation in the operations it conducts – the types of enemies it faces, the resources it has to draw upon, the capabilities it can deliver, the manner in which it coordinates with other branches of the armed services, and the organizational structures it uses to bring those new resources and capabilities to bear against a new generation of enemies. To accommodate this rapid transformation, a revolution has been occurring that began with the development of the concept of "network-centric warfare" (NCW). NCW promises to deliver unprecedented operational tempo and situational awareness through networked connectivity. For the Navy, the NCW concept has evolved into the definition of FORCEnet as a future organizing principle. FORCEnet is viewed as the operational construct and architectural framework for naval warfare in the information age, integrating warriors, sensors, command and control, platforms, and weapons into a networked, distributed combat force. It is envisioned that FORCEnet will provide the architecture to increase combat capabilities through aligned and integrated systems, functions, and missions. Like NCW in general, it promises to improve situational awareness, accelerate speed of decision making, and greatly distribute combat power.

Given this rapid transformation, several questions emerge regarding how best to realize the FORCEnet vision. These questions involve issues such as organizational design, information flow, information filtering, and display technologies. Accordingly, in this report, we describe an effort to develop an integrated testbed to explore FORCEnet concepts and technologies. The testbed is unique in that it serves to unite research on novel FORCEnet architectures with research designed to develop innovative information displays to support network-centric operations. Our intent in this report is to briefly describe this testbed, which will enable future experimentation and validation of emerging concepts.

We introduce the testbed below by briefly addressing the Adaptive Architectures for Command and Control and the *Command21* programs, which serve as the basis for the testbed and planned research. We then describe the testbed and present initial results from a recent demonstration of its capabilities.

The *A2C2* Program

The Adaptive Architectures for Command and Control (*A2C2*) program is ideally positioned with theories, methods, findings, and tools that can directly support the study and evaluation of this rapid change in naval operations. The *A2C2* program is a collaborative effort, coordinated by Aptima, Inc., and sponsored by the Office of Naval Research. The program embraces multiple partners including the U.S. Naval War College, Naval Post Graduate School, University of Connecticut, Carnegie Mellon University, George Mason University, and Michigan State University. The objective of the *A2C2* program has been to explore novel command and control organizational designs that support emerging FORCEnet concepts. Indeed, from the beginning, *A2C2* was envisioned as a program to develop organizational structures that would be adaptable, possessing the ability to rapidly change to meet the demands presented by new enemies and new missions. Hence, *A2C2* is now in a unique position to advance the military's understanding of how its C^2 organizational structures can evolve in new directions to take advantage of network connectivity to conduct new types of operations. In particular, over the last several years, the *A2C2* project has explored many new organizational structures, concepts, tools, and displays to aid the warfighter in organizational adaptation and effectiveness. Two components of the testbed are highlighted below that were developed as part of the *A2C2* program: the *A2C2* Distributed Dynamic Decision-making Simulation and the *A2C2* Decision Support System.

The A2C2 Distributed Dynamic Decision-making Simulation

The cornerstone of the *A2C2* program is model-based experimentation, in which models of organizations are utilized to define operational concepts, hypotheses, and scenarios that can be evaluated through experimentation involving human participants (see Kleinman et al., 2003). Experimental study of these organizations has been conducted using the Distributed Dynamic Decision-making (DDD) simulation. The DDD application is a versatile distributed multi-person simulation and software tool for understanding command and control issues in a dynamic team environment (Serfaty & Kleinman, 1985; Kleinman & Serfaty, 1989). The application offers flexibility in that it provides the ability to simulate different domains and scenarios to study realistic and complex military team decision-making. The DDD team-in-the-loop simulation environment has already been proven as an effective test-bed for conducting experiments in adaptive architectures for Joint Task Force (JTF) missions (e.g., Diedrich et al., 2003; Entin et al., 2003). Figure 1 shows a full-screen snapshot of the DDD running the JTF scenario used as a basis for Diedrich et al. (2003) and Weil et al. (2004) to study aspects of organizational adaptation. In general, the DDD provides an extensive set of capabilities for supporting experiments of teamwork in the military. The current generation of the DDD is a distributed real-time simulation environment implementing a complex synthetic team task that includes many of the behaviors at the core of almost any multi-person mission: assessing the situation, planning response actions, gathering information, sharing information, allocating resources to accomplish tasks, coordinating actions, and sharing or transferring resources.

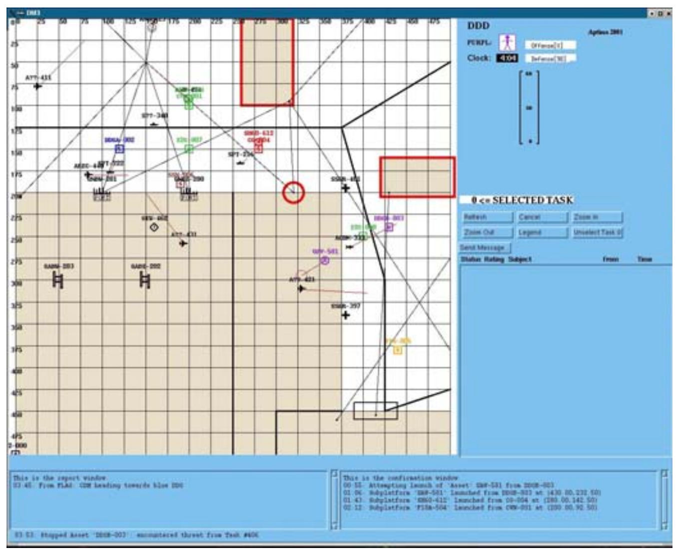


Figure 1. DDD Simulation.

The A2C2 Decision Support System

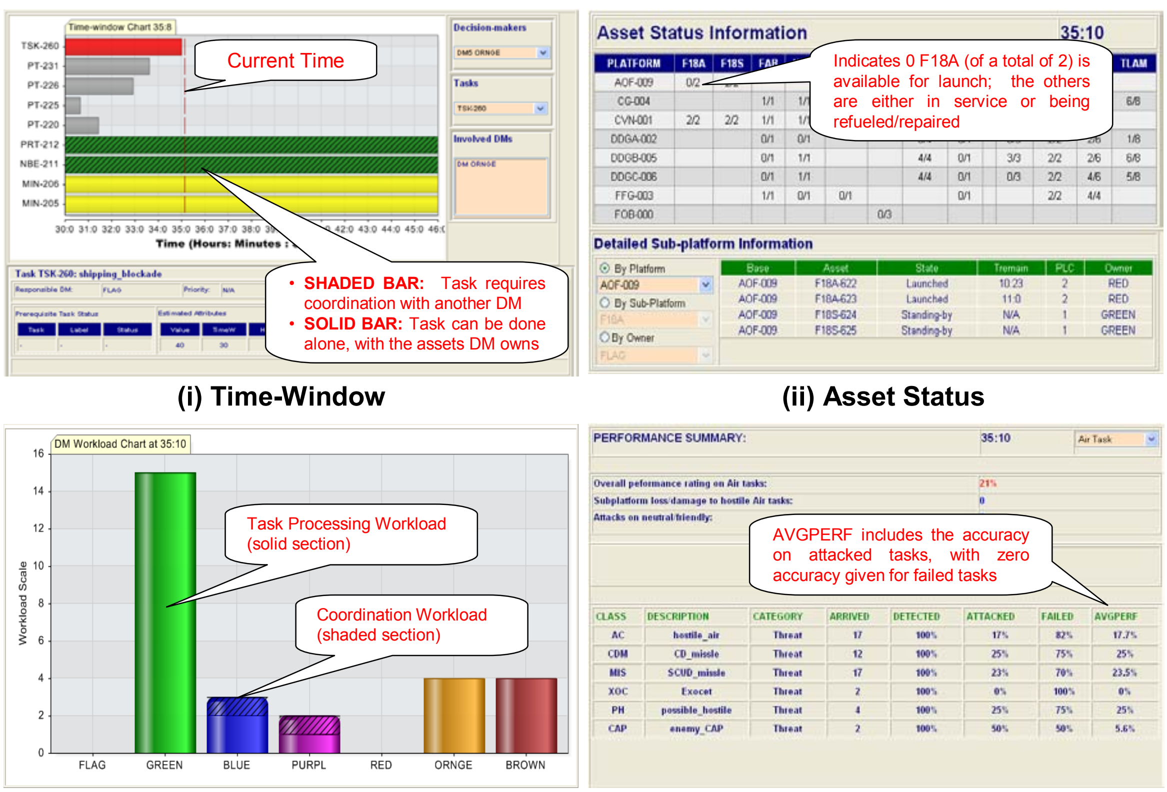
As a key part of the *A2C2* program, and critical to the system outlined here, the University of Connecticut and the Naval Postgraduate School have been working on the development of a Decision Support System (DSS) (Meirina et al., 2004) to facilitate decision-making and adaptation in the organizational structures studied in the *A2C2* project. In essence, the DSS aims to enhance organizational awareness and decision making by providing real-time information relevant to the organizational structure, organizational adaptation, organization process, and environmental attributes of the battle-space and mission. The DSS is envisioned as a prototype for supporting organizational adaptation in network-centric operations.

The DSS tool incorporates synthetic agents that provide interactive "what-if" analyses to provide richer information content and reduce cognitive load. The agent-driven DSS prototype provides four display areas as follows:

1. **Time Window:** contains real-time task-related information, which is customized for each specific decision maker (DM). See Figure 2.i

- Time-window chart: provides real-time data updates for tasks, whose resource requirements and attributes match those of the specific decision maker, i.e., the owner of the Time-Window display. The colors of the displayed task-bars indicate the status of the tasks, i.e., green – to be processed, blue – being processed, red – missed, and grey – completed. Shaded task-bars suggest DM–DM coordination requirements.
- Task information: provides detailed information for a selected task, which includes resource requirements for task execution, attributes, and an estimate of available time left to process the task.
- Coordination requirements: indicates coordination requirements among listed decision makers to process a selected task.

2. **Asset Status:** contains real-time information on the status and availability of assets. See Figure 2.ii.
   - Asset availability: the rows hold the list of the platforms (e.g., ships) and the columns show the list of the sub-platforms (e.g., Aircraft). The platforms – sub-platforms table indicates the number of available sub-platforms from the number of available platforms.
   - Sub-platform information: provides detailed information on sub-platforms, viewable by platform, sub-platform, or DM-owner. The information includes the platform locations, availability status, estimates of waiting periods, and ownerships.
3. **Decision Maker Workload Chart:** illustrates organizational process measures. See Figure. 2. iii. This type of displays allows the decision makers to asses their individual decision making in comparison to that of others to facilitate organizational adaptation.



(i) Time-Window

(ii) Asset Status

(iii) Decision-maker Workload

(iv) Performance Summary

Figure 2. The Decision Support System for the DDD

4. **Performance Summary:** indicates the overall assessment of organizational performance. See Figure 2.iv. This display illustrates another trigger for organizational adaptation.

The agent-driven DSS prototype is designed to provide critical information to the decision makers, in real time, thereby facilitating more effective decision-making and collaboration through improved situational awareness. Figure 2 provides screen shots of the display windows depicting the four DSS display areas. This prototype provides a starting point for research on how best to display these types of information to facilitate adaptation and improved team performance.

The *Command21* Program

In addition to the DDD and DSS, the project outlined in this report sought to integrate the *Command21* Research Program (Feher et al., 2003; Smallman et al., 2001). The *Command21* project offers a platform for integration of displays designed to support NCW with the *A2C2* research program. The Office of Naval Research sponsored the *Command21* project, managed by SPAWAR Systems Center, San Diego and supported by Pacific Science & Engineering and SPAWAR has developed an innovative concept known as the Knowledge Web (K-Web) and supporting technologies such as the K-Wall and K-Desk. K-Desks were used as part of the integrated testbed discussed here. The K-Desk is a six display system that utilizes web-based technologies to integrate mission relevant information, tools, and displays to facilitate group interaction and augment decision-making (Pester-DeWan et al., 2003). Mission relevant information is graphically displayed in easily viewable HTML formats thought to support decision making. The type of information displayed in each of the displays of the K-Desk can be chosen by the commander from a number of available displays for maximum flexibility and customizability. In this way the tool facilitates the utilization of the myriad of information available under emerging network-centric operations. A picture of the K-Desk is provided in Figure 3. Critical for the needs outlined here, the K-Desk enables the study of emerging FORCEnet concept via displays designed to support the next generation of information sharing.

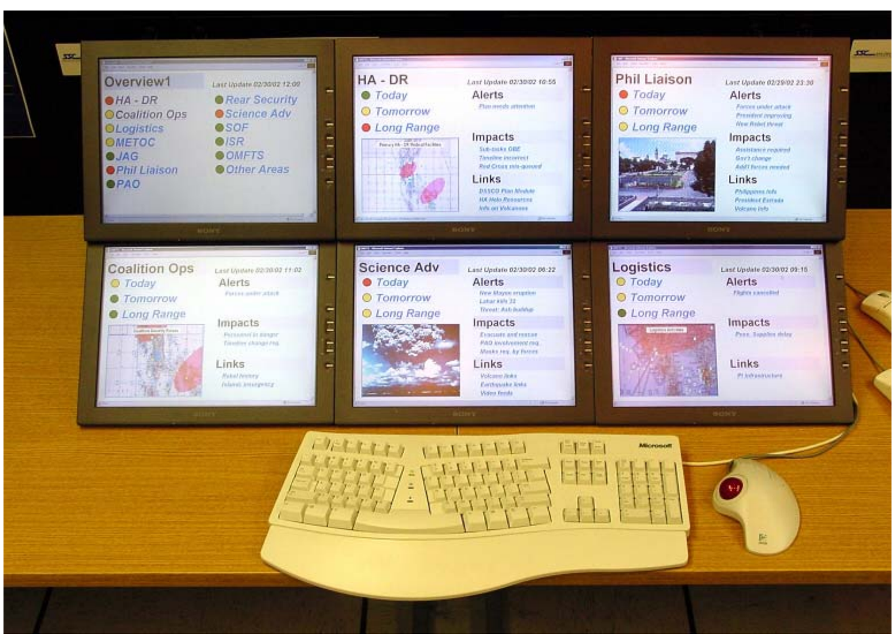


Figure 3. Knowledge Desk Display System

Knowledge Web (K-Web): The *A2C2* and *Command21* Integrated Testbed

By bringing these three components together, our objective in the work reported here was to develop an integrated testbed with sufficient operational fidelity to study FORCEnet concepts and tools in a laboratory setting. The A2C2 project made available novel organizational structures, decision-support tools (i.e., DSS), and the DDD team simulation. The *Command21* project provided an operationally relevant platform (i.e., K-Desk) for integration and dissemination of shared mission-relevant knowledge and tools that are customizable based upon the needs of the individual commander. The result of the integration is the framework depicted at a higher level in Figure 4. The next section identifies the technical aspects of integrating of the DDD, DSS, and K-Desk.

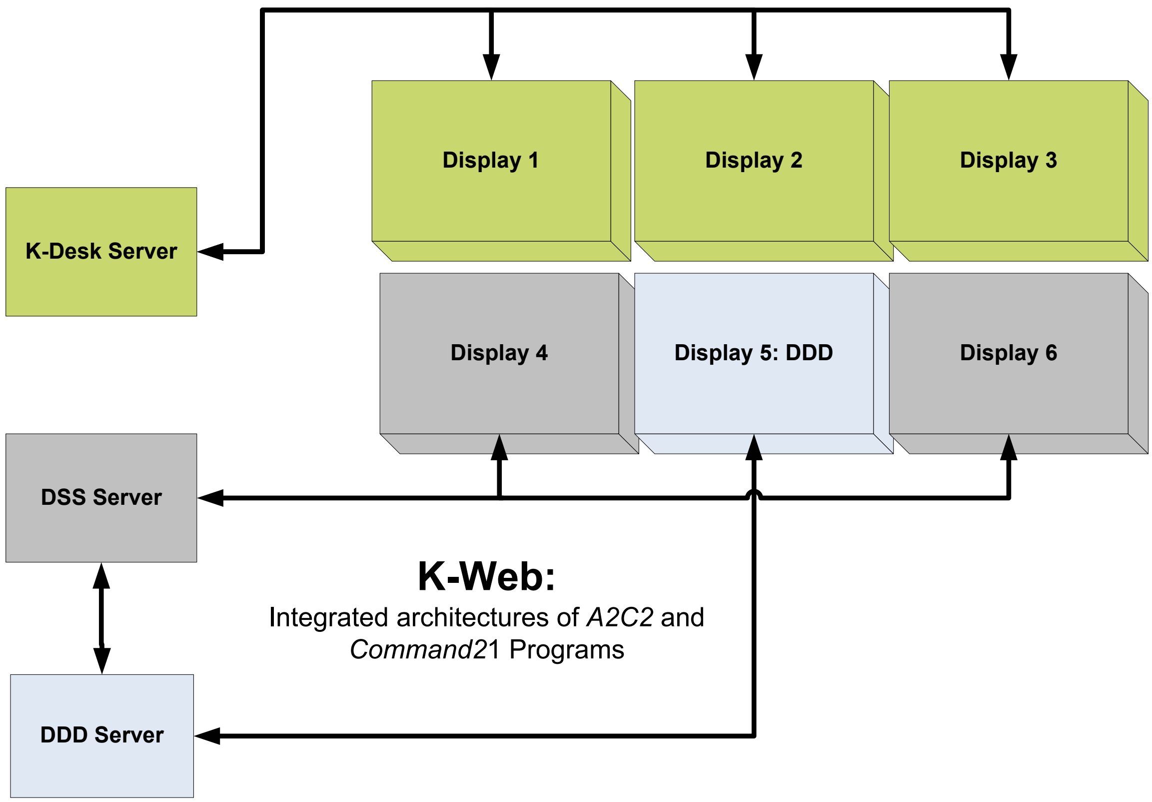


Figure 4. Diagram of K-Web integration

Technical Aspects of Integrating the DDD, DSS, and K-Desk

In order to create an integrated system that incorporated the DDD, DSS and K-Desk, it was necessary to develop a new software infrastructure that would allow for data to be accessible from the DDD by the DSS in real-time. This was a challenge given that these two systems work under different operating systems: the DDD operates under Linux, while the DSS is a Windows application. In addition, the DSS utilized an existing database (DB) that would have to be populated in real-time in order for the DSS to function properly.

To address these challenges, we developed new functionality that allowed the DDD to communicate with windows-based client applications through an existing mechanism called the DDD External Conduit (DEC). With this infrastructure in place, we then developed a new client application, called the DDD State Module, that modeled the DDD dynamic state information based on messages received from the DDD (via the DEC) that could in turn share those data with other windows-based clients. We then developed another client application, called the DB Module that could take this dynamic state information and populate the DSS database. These different integrated capabilities are shown in Figure 5.

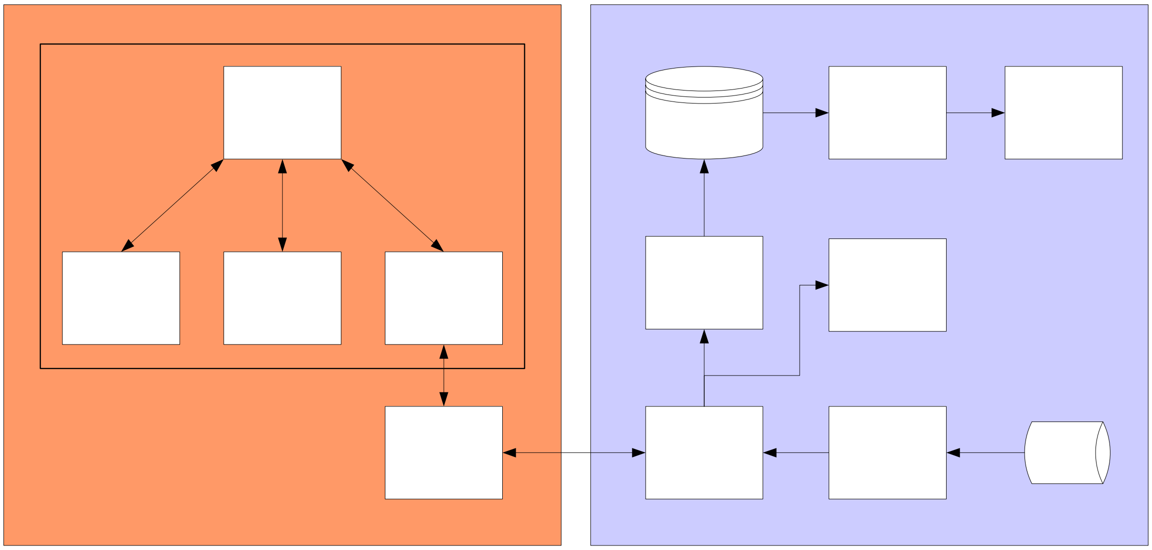


Figure 5. DDD Interface and Support Modules Design

The DSS synthetic agents would then use those data to generate and update the four information displays described above. Integration of the DSS information displays within the K-Desk was straightforward given their implementation as web-enabled Active Server Pages.

Based on this design, we sought to demonstrate the feasibility of this testbed as well as assess user acceptance and obtain initial feedback. We therefore conducted a demonstration of the system in August of 2004 at the U.S. Naval War College.

Method

Participants

Twelve officers served as participants in the demonstration. All participants were Lieutenant Commanders or higher and were students at the U.S. Naval War College in Newport, RI. The twelve officers were organized into two teams of six individuals each for two separate data collection sessions.

Simulation Environment

From the perspective of the participants, the simulation environment was built on the integrated test bed or Knowledge Web (K-Web). For the purpose of the demonstration, the K-Web was the integration of the K-Desk, the DDD, static mission-relevant information (e.g., mission plan, etc.), and the DSS. Each of the six K-Desks (one for each team member) consisted of six video displays, two mice, and supporting software implemented in a single testing room at the U.S. Naval War College. The DDD simulation was presented on a central display of the Knowledge

Desk. The remaining five displays were used to display mission relevant information and the graphical information provided by the DSS. The DSS provided dynamic information about team and individual performance. One mouse manipulated the static and dynamic information displays and one was used by the DDD simulation.

Organizational Structure and Mission Manipulation

For the purpose of this demonstration, the methodology described by Diedrich et al. (2003) was followed so that the efficacy of the integrated testbed could be assessed using a well-understood scenario and organizational structure. In this case, a single organizational structure (Functional organization, F) was employed, which was characterized by the types of assets within each team member's control. In this demonstration, each participant was given control of functionally similar assets that were dispersed throughout the mission battle space; for example, they might be given all the Intelligence-Surveillance-Reconnaissance or all the Strike assets.

Using this structure, each team participated in two data-collection sessions. Scenarios were developed that were either well suited to the F organizational structure (functional scenario, f) or not well suited to the F organizational structure (divisional scenario, d). A mission was considered to be congruent if the team's organizational structure was matched with its associated scenario (i.e., Ff). In contrast, a session in which the team and the scenario structure were mismatched was considered incongruent (i.e., Fd). Congruence was achieved by defining task requirements within a scenario that matched the asset capabilities of the organizational structure to varying degrees, thus reducing (Ff) or increasing (Fd) the need for coordination among players; see Diedrich et al. (2003) and Entin et al. (2005) for complete details.

Procedure

Participants were briefed on the purpose of the demonstration and demographic information was collected. Participants then received training on the battlespace simulation generated by the DDD. They received DDD "buttonology" training (i.e., how to use the simulation) followed by training designed to provide the skills necessary to perform the scenarios in a team environment. Training on the displays of the K-Web occurred independently of DDD training. Instruction on the scenario-specific background information was presented as information related to the mission (e.g., road to war, commander's intent, tasking order, etc.). Before the first scenario, participants received a briefing on the DSS and the importance of the information it provided.

The first scenario was designed to be congruent with the organizational structure the team had been assigned (Ff condition). The mission was to prepare the battlespace for the insertion of follow-on forces using land, sea, and air assets. There were several objectives, including the destruction or capture of a command center, two air bases, two naval bases, and a final port. In addition to fixed objectives there were targets of opportunity, such as missile launchers that had be identified and engaged before they fired. Communication among team members was emphasized as well as the use of communication discipline (e.g., the use of call signs and brevity). In contrast to previous work (e.g., Diedrich et al., 2003), all scenarios were conducted at half normal speed to facilitate use of the DSS and K-Desk information.

At the completion of the first scenario, an after action review (AAR) was conducted to discuss team performance and lessons learned. An intelligence brief was then presented to the participants to explain that the enemy had changed their tactics based upon the strategies employed by Blue forces during the first scenario. The mission task requirements had changed resulting in the need for new coordination and/or collaboration strategies to prosecute tasks. This change in mission task requirements represented a shift in the design of the scenario making the second scenario incongruent with the organizational structure the teams were using, producing the Fd condition. A small strategy session occurred based upon the Intel brief and task graphs to allow the team to plan task prosecution during the second scenario. At the end of this scenario a second AAR was conducted to discuss outcome and attitudes.

Measures

The measurement focus for the demonstration was on feasibility of integration, user acceptance, and user perceived value. The feasibility of integration examined the integration of software components and the capabilities of those individual components to meet the challenges presented by the experiment tempo, in particular the database capabilities and communication between the components. User acceptance and perceived value were assessed both during the demonstration through observation of screen use and at the completion of the experiment using an AAR. Some of the talking points used during this AAR included:

- Overall benefit, what impact did this set of tools have on:
    - Decision making: To what extent, if any benefit will this group of technology have on your ability to make decisions
    - Workload
    - Ability to improve situational awareness
    - Value of concurrent viewing: benefit of being able to see multiple sources/views of information concurrently
    - Information utility: what information was the most useful from all the systems as well as displays that were useful or were not useful.
- Recommendations

Results

Successes

The demonstration was successful given the challenges faced; namely the integration of complex software into a feasible and operationally relevant test environment. Critically, the overall system performed well, the system was stable, and user acceptance was high. Participants felt that the tools facilitated decision-making by providing information that improved their ability to coordinate the planning and distribution of assets. Participants referred to information regarding resource requirements, asset ownership, and task precedence so that they could "keep straight who owned what" as well as know what assets were available to coordinate the prosecution of tasks. Participants used the information to prioritize placement of assets as well as ensure that assets were available when required.

Additionally, participants felt they had increased situational awareness, particularly through the use of the decision support tools that provided performance feedback as well as mission status information. Only when they had to zoom in to prosecute a task did they feel they were at risk of loosing situational awareness. The process of "zooming in" is a common practice within the DDD when selecting a desired task for processing.

Zooming in is often a required step by the user due to other assets or tasks being in close proximity to the desired task making the selection of that task difficult.

Observations

Observations of team member's information use indicated that a majority of team members were using both decision support and mission-relevant information to facilitate task execution. Team members also changed the type of information displayed as circumstances necessitated. In addition, many would leave a screen either blank (information minimized) or have the main menu displayed if they were not using the display. The screens may also have been made blank to limit distraction. This type of use and non-use indicated that the individuals were utilizing the quantity of screens to their advantage. Observational data also indicated a preference for weapons/assets status display. Participants presumably displayed mission-relevant information in order to facilitate task and mission execution. In addition to the weapons/assets status display, one team displayed the performance summary screen almost as frequently, perhaps in order to maintain situational awareness of what tasks had been completed and what yet remained to be prosecuted. Almost all of the different display types were used at one time or another, with preferences apparently driven by the type of position the participant played.

Workload varied somewhat for the different positions, but participants reported that they felt the integrated system reduced workload by making information more accessible. This accessibility helped individuals anticipate increases in workload due to changes in the simulated battlespace so that they could have assets ready and/or in place to deal with upcoming events. Workload information was available to all of the participants in many forms (e.g.; taskload, asset availability, timeline). In addition, this provided team members with increased awareness of fellow team members' workload, reportedly allowing more effective coordination.

Participants recognized the benefit of the integrated suite of network-centric tools and utilized these tools to effectively prosecute tasks. They used their ability to view a variety of information concurrently to maintain situational awareness and make more appropriate decisions through more appropriate coordination. Team members stated that they liked the idea of being able to display information concurrently. When asked about the number of displays the majority of participants felt that the quantity of displays was reasonable as it afforded flexibility. Some team members felt that the number of display screens was a little too high. Those team members who felt that the number of display screens was high agreed that the ideal number of displays would be four.

Some Challenges

A majority of participants felt that a lot of information was displayed and there was only a limited amount of time available to digest it, and that they needed to spend a fair amount of time learning the types of information available. These comments highlight a common problem in network-centric warfare – a tendency toward information overload. Information management training would afford some help as would intelligent filtering and targeting of incoming information. As is readily apparent, these issues reflect a primary research need to support FORCEnet.

Many participants expressed a preference for the timeline and precedence graph displays (the display that shows what tasks must be completed before other tasks can be processed). They felt that this display helped in maintaining good SA and helped planning for future demands. Although the weapons/assets status was used frequently, many participants stated they would have liked to see the graph provide information on ammunition availability, as well. Another position voiced by some was that the DSS displays were overly complex; by the time they figured out what information the display was conveying, they could have derived the same information from direct observation of the ongoing tactical situation. This indicates that the usability of the DDS displays must be improved and that training to use and understand the DSS displays also needs improvement.

Discussions indicated that several participants felt the necessity for two displays for the DDD simulation; one display to zoom in on a particular task to be prosecuted and one display to maintain a global view. When it was pointed out that the large screen at the front of the room displayed a global view, participants noted that a display at their consul would be easier to use. A technology that the participants felt was missing was the opportunity to use chat or instant messenger. It was noted that aboard ship chat is used frequently and often individuals will have more than one conversation going at a time. To many participants the use of verbal communications is reserved for action items and not for general communications.

Conclusion

In summary, these demonstration results indicate that the integration process was a success and that a viable testbed to investigate FORCEnet concepts, processes, and technologies is at hand. In particular, the testbed showed the potential of providing war fighters with an integrated information-rich environment to support mission execution, and as such, a glimpse into the promise of NCW. The integration of the agent based DSS and K-Desk was successful and participants readily embraced the available information and technology. Moreover, the participants felt the available information and technology facilitated the completion of tasks and the overall mission. Based on these results, we plan on using this testbed to further explore emerging FORCEnet technologies and concepts.

Several improvements are planned which will increase the effectiveness of this testbed. These include increasing the response time of the decision support graphics to strengthen the association between the simulation and DSS, as outlined in the results section. Interface improvements, such as a more intuitive 'zoom' feature and operationally relevant iconography will improve simulated mission performance. A deeper integration of the DDD with the K-desk and DSS would increase the types of information that can be presented to the user. Finally, we are in the formative stages of developing computer-based agents that can serve as adjuncts to the human participants in the DDD simulation. This will allow the investigation of organizational structure and adaptation in larger organizations, with dozens of team members.

These improvements will allow us to examine organizational designs in modern military organizations such as the Expeditionary Strike Group (ESG), based on emerging FORCEnet concepts. The testbed being developed will allow researches to better understand the implication of various organizational structures, and could potentially allow research-based recommendations for novel organizational designs.

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