From Cognitive Task Analysis to Simulation: Developing a Synthetic Team Task for AWACS Weapons Directors

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Abstract

To effectively study team variables as they impact performance in a particular domain, it is possible to develop medium fidelity simulations that abstract some details of the performance environment while maintaining others. This paper reports the results of a successful effort to create a synthetic task environment that captures key elements of a team task, based on Cognitive Task Analysis of the important features of the task from a teamwork and cognition viewpoint. We studied the performance of AWACS Weapon Director (WD) teams and, based on the CTA data collected and insights from contemporary team theory, adapted an existing base simulation to mimic many of the crucial details of the task and its teamwork demands. The DDD simulator is a unique software tool set and computer system developed to study issues of distributed situation assessment and resource allocation in a dynamic team environment. As of this writing, we have we have run collected data using the DDD AWACS task and knowledgeable cadets from the US Air Force Academy. We are in the process of demonstrating that it is possible to strike a balance between highly complex, large-scale, high fidelity simulations on the one hand, and over-controlled, overly-simple laboratory research tasks on the other. Results of our research will inform team theory, system and organizational design, and continued research in the laboratory and field. [1]

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1 Problem Description and Relevance to C2

The complexity of team interactions and the environments in which they perform makes it difficult to empirically study teams in controlled experiments. Particularly when the teams we are interested in studying typically perform in rich environments with many naturally occurring performance-effecting variables, it can be difficult to separate the performance effects of individual aspects from the tangle of interacting factors in the environment. To offset some of these difficulties, many researchers have turned to simulation technologies in an effort to create enough realism to stress expert teams, yet control enough environmental noise to collect clean team-performance results. In the military, these simulations are often high-fidelity "copies" of actual field systems, backed by network-coupled control stations and semi-automated force models to provide troops with very realistic, full immersion performance experiences. These simulations often end up being as complicated as the environments they were meant to model.

To effectively study team variables as they impact performance in a particular domain, it is possible to develop medium fidelity simulations that abstract some details of the performance environment while maintaining others. To create a reasonable analog of any team performance environment, however, requires very careful analysis of the task and environment to insure that the variables that might have impacts on team performance, are preserved while others, that are not likely to influence team performance are abstracted out of the simulation. Design of this type requires a very thorough understanding of the task and environment. It also requires that information about the task be interpreted through the lens of team-performance theory and models. These data and theory, together, can be used to decide which among the many possible variables that might be modeled are the important variables required to capture the teamwork and coordination demands of the task under consideration.

Cognitive Task Analysis (CTA) is an effective method for eliciting information about the decisions made and the information used by experts in performing their jobs (Gordon & Gill, 1997). While it seems obvious that CTA results should be helpful in creating simulation-based task environments that capture key cognitive elements of real-world tasks, the bridge between CTA and simulation has not been well established. This paper reports the results of a successful effort to create a synthetic task environment that captures key elements of a team task, based on Cognitive Task Analysis of the important features of the task from a teamwork and cognition viewpoint.

The domain of application is AWACS command and control. We studied the performance of AWACS Weapons Directors (WD) teams and, based on the CTA data collected and insights from contemporary team theory, adapted an existing base simulation to capture many of the crucial details of the task and its teamwork demands. Essentially, AWACS operators are air-traffic controllers in the sky: They direct blue fighters to do such things as intercept targets, refuel with airborne tankers, run strike missions, and return to base. AWACS teams typically consist of three or more WDs supervised by a Senior Director (SD). The SD is responsible for configuring the weapons team based on the mission, reporting any problems to individuals outside of the section, taking over for overloaded, overwhelmed WDs, and performing other important missions within the mission (i.e. search and rescue efforts).

WDs must coordinate as a team while simultaneously monitoring and acting on incoming information in a very dynamic mission environment. They must coordinate resources (including knowledge, assets under their control, and information) and must maintain an accurate mental model of a rapidly changing world. We have shown that it is possible to capture many of these demands in a medium fidelity simulator, and we are currently in the process of validating this simulation to show that the data and insights it will provide as a lower cost, higher-control research tool can generalize to higher fidelity simulation and to the field.

2 Approach

The goal of our work has been to develop and validate a medium fidelity simulation of AWACS command and control using a process of focussed CTA of the domain, model-grounded conversion of CTA data into a reasonable minimum set of requirements for a simulation, software development, and finally, validation of the medium-fidelity simulation using expert participants and high-fidelity or field-gathered data for comparison. We are in the process of demonstrating that it is possible to strike a balance between highly complex, uncontrollable exercises, on the one hand, and over-controlled, overly-simple laboratory research on the other. Further, we are currently working to collect data that can be directly compared to data from a higher fidelity simulation (C3STARS, at Brooks AFB) to show that our approach provides data that generalize to the field.

2.1 AWACS Command and Control

During the first phase of this work, CTA interviews were performed using expert WDs (MacMillan, Serfaty, Thordsen, Klinger, Cohen, Freeman, & Elliott, 1997). The goal of this CTA was to identify the major cognitive tasks performed by the WDs, the information used in those tasks, the elements of team interaction that are most central to the WD team, and the characteristics of team interaction that distinguish the WD team from other teams that perform resource allocation tasks. Several key insights were gathered at this stage that allowed us to adapt a reasonable medium-fidelity simulation. For instance, we learned:

WDs operate in an environment in which teamwork is of paramount importance. Not only does the success of a mission often hinge on the ability of the weapons team to handle the situation, but lives hang in the balance as well. A good weapons team can handle the difficult fast-paced tasks that are presented to them in every mission. In contrast, the team that is still figuring out who talks to whom, who is responsible for what, and how to pass information is headed for disaster.

WDs and the SDs establish contracts with one another prior to a mission. These contracts are quite distinctive to the AWACS WD team, although it is not uncommon for well coordinated teams to take advantage of quiet periods in order to make agreements about how they will handle tasks during more stressful periods (Orasanu, 1990). Contracts for the AWACS team may include: when the check-in controller turns aircraft over to the Area of Responsibility (AOR) controller, how the team will handle the hand-offs when aircraft go to tanker, how to react to a search-and-rescue mission, etc. If the team has not dealt with these issues prior to boarding the aircraft, they will be caught off guard once they are on station.

These and other insights provided us with an understanding of the tasks AWACS teams face, the teamwork demands that shape performance, and the role of their individual taskwork in overall workload. We coupled these insights with expert advice about the form and pace of events WDs monitor and control through their individual computer consoles and communication equipment, and developed an AWACS simulation.

2.2 Simulation Development

The results of the CTA interviews were used to configure a team-task simulation testbed that captures the most essential elements of the AWACS Weapons team performance. Implications of the CTA for the design of our synthetic AWACS task included:

- The simulation must be flexible in allowing multiple configurations for the division of responsibilities among team members. AWACS weapons teams differ in the way that they divide responsibilities.
- Team members must be able to take over tasks from other, overloaded, team members.
- Team members must be able to discuss division of responsibilities and form "contracts" before they begin a scenario.

Based on the results of the CTA, we modified an existing distributed team-in-the-loop simulation, the Dynamic Distributed Decisionmaking (DDD) simulation (Kleinman, Pattipati, Luh, and Serfaty, 1989; Kleinman and Song, 1990; Kleinman, Young and Higgins, 1996) to represent the most important elements of the AWACS WD team task.

The DDD simulator is a unique software tool set and computer system developed to study issues of distributed situation assessment and resource allocation in a dynamic team environment. Essentially, the DDD is a team-in-the-loop simulation core that can be used to model many different environments and then used to study important team-oriented cognitive processes and tasks, including situation assessment, resource allocation, and decision making. The DDD simulator has been a major component of a team research program that has been underway for almost 15 years(Serfaty & Kleinman, 1985; Kleinman & Serfaty, 1989, Serfaty, 1996).

In a typical DDD scenario, a team of decision makers must make coordinated decisions based on uncertain, ambiguous, and sometimes decentralized information. Each team member has only a portion of the information and/or resources needed. Figure 1 shows a configuration for a four-person team—one leader and three subordinates—with typical DDD team decision-making tasks. A team task such as the one illustrated in Figure 1 re-creates many of the cognitive demands associated with team decision making and cooperative work. The DDD simulation task is designed with a flexible structure that can be manipulated to vary a number of different elements of task complexity (e.g., risk, uncertainty, time-pressure, information distribution, communication structure.) The DDD software provides real-time control, on-line data

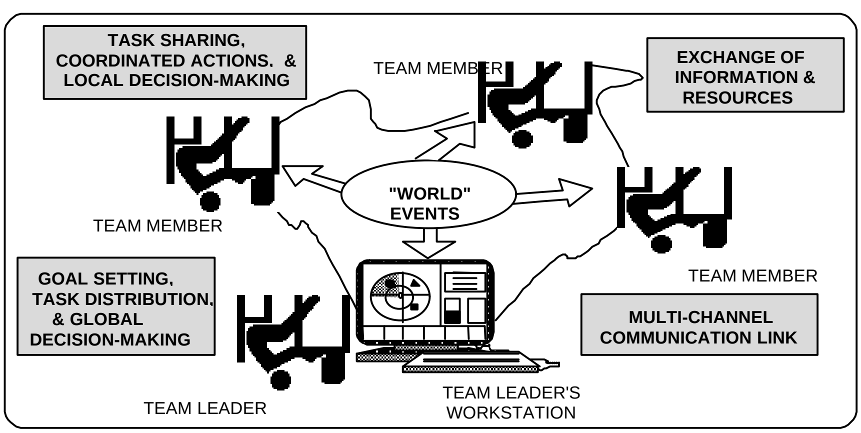

Figure 1. Typical DDD Configuration

collection, an interactive display/interface. In the current context, we demonstrated that the DDD, with modest changes, could represent the team tasks of AWACS Weapons Directors. We used CTA data and expert advice from AF personnel to develop a medium fidelity analog of the Weapons Director console. The resulting task supports an n-player game of WDs monitoring and controlling resources and tasks in an airspace. The simulation provides total control over scenario design, team organization, and data collection. As a next step, we are validating this simulation and developing a team-performance tools package that includes empirically tested measures, models, results, and specific guidelines for effective team-support interventions.

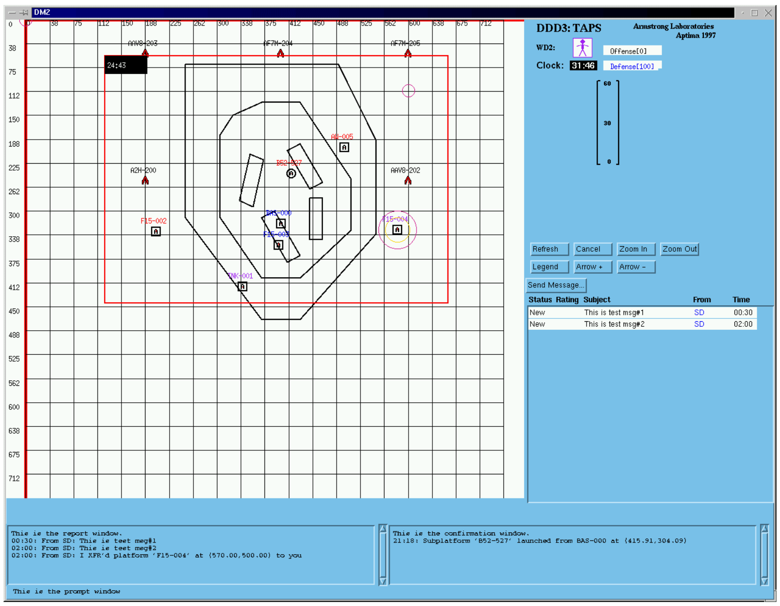

Figure 2. DDD AWACS Display

3 Results

The resulting AWACS-DDD simulation captures the key variables needed to study AWACS command and control teams in a more controllable, faster turnaround environment with enough richness to tax even expert players, but enough control to support targeted research. The current version of AWACS-DDD captures many key detail found in the actual AWACS Command and Control team environment. We have simplified some aspects of the task while including other aspects that theory predicts will have maximum impacts on team performance. Examples of details that we have captured include:

- different types/classes of hostile aircraft,
- different types classes of friendly assets with different characteristics such as endurance,
- sensors on-board friendly aircraft that may obtain information not available to the AWACS directly,
- ability for an aircraft to pursue a track (using an intercept geometry),
- modeling a sensor platform (e.g., AWACS),
- introducing hostiles at prescribed times to fly on user-selected trajectories,
- hostiles that can attack the team’s assets as well as defended areas,
- friendly air bases from which aircraft are launched and can return for resupply,

- ground targets (for a strike package),
- SAM threats,
- SCUD launchers (detected only when a sensor is in close proximity) capable of firing a missile at a defended site,
- ability to assigning specific tasks to a specific WD (as might be done by the SD),
- ability to transferring control of assets among WDs,
- ability to modifying team member’s responsibilities, and
- ability to change a task’s priority.

An example display for the DDD AWACS simulation is given in Figure 2. The large grid region that takes up the majority of the left portion of the screen is the map over which aircraft are animated when the game is running. This map is the region of the screen where most player actions take place. In this image, the map depicts an island surrounded by a defined buffer boundary. The symbology imposed on the map represent friendly and enemy aircraft currently in view. Known hostile tracks are represented in red, unknown but detected aircraft are represented in yellow, and friendly aircraft are represented in green with colored labels indicating player ownership. Orbit-points and aircraft destinations (the coordinates that a player instructed aircraft to move toward) are indicated by small red circles. Aircraft are shown using standard symbols. The lines on these symbols are track vectors that point in the track's current direction and have a length that increases with the speed of the track. The buttons on the right and bottom sides of the screen have been implemented with virtual-action buttons to mimic the AWACS functionality and a simple email system for team communication.

The next step in the research will be to use the DDD AWACS testbed to experimentally test interventions aimed at enhancing team strategies, cognition, and performance, including shared displays, teamwork support systems, team procedures and team training modules. Results will be used to guide the design and training of future team-based systems. The goal will be not just to prove that an intervention works, but to understand *why* it works so that the results can be generalized to other kinds of teams.

As of this writing, we have we have collected but not yet completed analysis of data from an experiment in which DDD AWACS scenarios were executed by knowledgeable cadets from the US Air Force Academy. Our initial research was focused on the organization and distribution of responsibilities in the AWACS team and the impacts of changing workload on performance under different team architectures. Our preliminary results are encouraging. The task was extremely engaging, and produced an engrossing team experience. We collected embedded performance measures, survey data and observational data to provide a complete picture of team process, performance, and outcome. These preliminary data will provide a baseline for future experiments as well as insights into AWACS team function.

4 References

Gordon, S.E. & Gill, R.T. (1997). Cognitive task analysis. In Zsambok, C.E. & Klein G. (Eds.) Naturalistic Decision Making. Mahwah, NJ: Lawrence Erlbaum.

Kleinman, D. L. and Serfaty, D. (1989). Team Performance assessment in distributed decision-making. Proceedings of the Symposium on Interactive Networked Simulation for Training, pp. 22-27, Orlando, FL

Kleinman, D. L. and Song, A (1990) A Research Paradigm for Studying Team Decision-making and Coordination. In Proceedings 1990 JDL Symposium on Command and Control Research, Monterey, CA, pp. 129-135.

Kleinman, D. L., Young, P. W. and Higgins, G. (1996), DDD-III: A Tool for Empirical Research in Adaptive Organizations. Proceedings of the International symposium on C2 Research , Monterey, CA.

Kleinman, D., Pattipati, K. Luh, P., and Serfaty, D. (1992). Mathematical models of team performance: A distributed decision-making approach. In R. Swezey and E. Salas, (Eds.) Teams: Their Training and Performance (177-218). Norwood, NJ: Ablex Publishing Corporation.

MacMillan, J., Serfaty, D., Thordsen, D., Klinger, D., Cohen, M., Freeman, J. & Elliott, L. (1997). A System to Enhance Team Decision-Making Performance, Phase I Final Report. Woburn, MA; Aptima, Inc.

Orasanu, J. M. (1990). Shared Mental Models and Crew Decision Making, CSL Report 46. Princeton, NJ: Cognitive Science Laboratory, Princeton University.

Serfaty, D. (1996). Adaptive architectures for command and control (A2C2): An overview. In Proceedings of the 1996 International Symposium on Command and Control Research, Washington DC.