Leveraging Human Behavior Modeling Technologies to Strengthen Simulation-Based C2 System Acquisition

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ABSTRACT*: An ongoing challenge within the DoD modeling and analytical community is the ability to accurately represent human behavior to a useful degree of realism. However, advances in human behavior modeling show promise for military simulation in general, and specifically for C2 modeling. The application of these emerging techniques could provide (1) a much-needed breakthrough in the realism of simulated C2 for analyses and decision aids, (2) a powerful extension for man-in-the-loop experiments where study cases are limited by operator availability, and (3) a potential mechanism for reducing support personnel requirements for military training exercises. Several architectures and tools exist for building models of human behavior. Although these architectures are maturing via non-military venues, there remains a void in the application of this technology to meet military needs. The key area that has yet to be directly addressed by current efforts is the application of this technology to time-critical command and control decision-making processes. The Air Force Research Laboratory (AFRL) has invested in pilot behavioral models that may have the potential for extension to C2 operators and eventually to teams of C2 operators.*

In this paper we describe a new experimentation program that will (1) leverage existing behavior models and tools as appropriate, (2) implement an experimentation facility for developing and assessing behavior models within a simulated battle context, and (3) extend these models to represent tactical C2 operator activities. The MITRE Corporation is executing this project in support of the Air Force Electronic Systems Center (ESC). During the first year of the project, the mission area focus of our prototyping effort will be the tasks performed at a Joint STARS operational console. If this approach to enhancing the simulation of C2 is found to be effective, the resulting models can be provided for analysis, experimentation, and training throughout the C2 enterprise (1) to supplement human behavior representation in existing simulations and (2) as a means to reduce man-in-the-loop event staffing requirements.

1. Introduction

This paper describes the rationale behind, and plans for, a new project that will explore the application of emerging behavioral modeling techniques within military simulations to better capture the cognitive and organizational factors that influence C2 operations. This project is entitled “Capturing Behavioral Influences in Synthetic C2” and is being executed by the MITRE Corporation in support of the Air Force Electronic Systems Center (ESC). Through prototyping and experimentation the project team will answer questions regarding (1) the potential of behavioral modeling methods to improve the realism of simulated C2 in analyses and decision support applications, and (2) the utility of these techniques as the basis for replacing man-in-the-loop operators in support of real-time experimentation and training exercises.

Initially the project team will assess the state of available modeling techniques to address the types of behaviors inherent in C2 operations. Then we will apply the most promising tools to selected C2 mission areas. Our initial prototyping focus will be on the development and validation of a single behavioral module or “software surrogate” that represents the actions of a Joint Surveillance, Tracking, and Radar System (JSTARS) operator within a mission-level battle simulation. These prototype efforts will bring highly regarded behavioral modeling techniques to bear on “real” military problems of critical importance as we move toward a more integrated C2 system of systems.

This paper begins by describing the motivation behind this research project and the potential for it and other similar efforts to positively impact simulation-based C2 system development applications. Then, a brief overview of the human behavior modeling “state-of-the-practice” is provided as background information, and related research efforts are described. The remainder of the paper is devoted to outlining the technical approach and planned schedule for the first year of the ESC-based project.

2. Motivation for Applying Human Behavior Modeling Techniques

At the ESC, the developing agency for many of the Air Force's C2 systems, simulation engineers have been using synthetic environments for several years to support C2 system analyses, training, and experimentation. The simulation tools employed are very effective at simulating the physical, system aspects of C2 -- the physics behind sensor performance, for example. Or the loading on comm networks and systems and resulting bottlenecks.

However, there is a human component to C2 that is becoming increasingly influential in battle outcomes that we do not model as thoroughly. Simulated decisions are often based on simple probabilities, and decision timelines may be modeled as fixed inputs that don't change as the C2 operator's environment and workload change. These simplistic representations of behavior are limiting the overall realism of simulated C2 as real-life battle outcomes are depending more and more on (1) wise decisions in an information-saturated environment, and (2) the ability to influence the enemy's perception of the battle.

ESC has recognized this need to apply behavior modeling technologies to fill this void in support of its life-cycle C2 system development efforts. Mission areas involving ESC-developed C2 systems that stand to benefit from improved behavior modeling include operations onboard AWACS and JSTARS aircraft and within the Time Critical Targeting (TCT) "cell" of an Air Operations Center (AOC).

This human behavior modeling deficiency is being recognized on a national level as well. These words were taken from a recent National Research Council (NRC) study: "...users of military simulations do not consider the current generation of human behavior representations to be reflective of the scope or realism required for the range of applications of interest to the military. The representations needed are ones that more accurately reflect the impact of human behavior and the decision process of friendly and enemy leaders at multiple levels of command within real-time constraints." The report goes on to assert, "the achievement of higher levels of realism requires significant understanding and application of psychological and organizational science." [NRC, 1998]

3. Potential Benefits to ESC and the Broader C2 Community

Figure 1: Simulation-based C2 System Development and Training Activities that Can Benefit from Improved Human Behavior Modeling

As illustrated in Figure 1, breakthroughs in the application of human behavioral modeling will benefit simulation users across the spectrum of C2 development use cases, including:

- ***Concept Development & Operations Analysis.*** Before a system is developed, simulations are used for concept development in the context of a simulated battle. Tradeoffs are identified and studied through operations analysis and man-in-the-loop experimentation. The Single Integrated Air Picture (SIAP) work is an example of a large ongoing project making heavy use of simulations for analysis. Similar analyses are continuing in many concept/mission areas such as time-critical targeting, multi-mission aircraft, and ballistic missile defense. Better human behavior representations in the simulations used for these analyses will improve modeling of situation awareness and decision timelines and provide more realistic battle outcomes & study results.

- ***Embedded Decision Aids.*** Simulations can be embedded in certain systems to play out "what-if" scenarios and help with battle planning. The ATO Mission Analysis Simulation System (AMASS) was one tool prototyped at ESC for a JEFX event. As these tools become more available to commanders, better HBR will allow them to provide more credible outcomes for influencing command decisions.

- ***Experimentation.*** Virtual (man-in-the-loop) simulations are being used in increasing numbers within constructive simulation environments to permit warfighters to participate in and influence such analyses. This is proving useful, but is expensive and constrained by the limited availability of suitable operators for the virtual consoles. A software surrogate that can be tailored to play the role of the man-in-the-loop allows analysis of the warfighter's role in additional scenarios and use cases beyond what human experiment subjects can be scheduled to support. The emerging Air Force Materiel Command (AFMC) *Joint Synthetic Battlespace (JSB)* and the Joint Strike Fighter (JSF) *Virtual Strike Warfare Environment (VSWE)* are examples of mixed constructive/virtual federations that can leverage this powerful *"agent-in-the-loop" mode of operation* to maximize and extend warfighter-in-the-loop experiments. In addition, application of behavioral modeling methods to these federations can provide added realism at key perception and decision points that sway mission and battle outcomes.

  Another emerging experimental facility is the CAOC-X project at Langley AFB, VA. The CAOC-X will contain a portion of an Air Operations Center (AOC) that can be manned and stimulated within experimental scenarios. One technical challenge for the CAOC-X is the representation of "the rest of the AOC"—that is, the workstations and hundreds of personnel not present at the CAOC-X that normally would be present in an operational AOC. Software surrogates that represent the behavior of these missing contributors are one possible solution to this challenge.

- ***Training.*** Additional realism can be achieved regarding the actions taken by simulated human entities in a training exercise. Furthermore, in exercises that employ a large number of auxiliary personnel to operate technical support consoles, the use of software surrogates could significantly reduce exercise manpower requirements. One emerging training application that stands to benefit from improvements in behavioral modeling is the *Joint Simulation System (JSIMS)*, which is being developed to support battlestaff training activities such as Blue Flag exercises.

4. Overview of Human Behavior Modeling Techniques

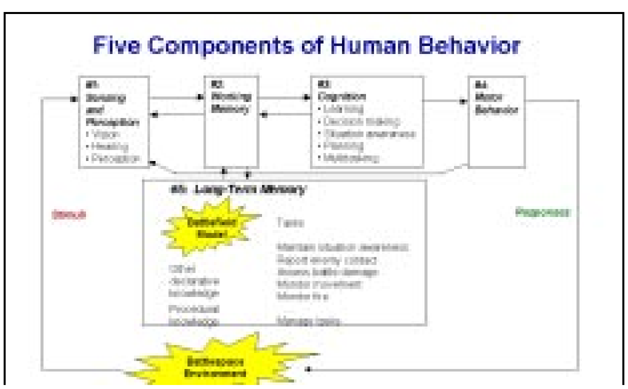

Figure 2. Five Components of Human Behavior

A framework for modeling human behavior is illustrated in Figure 2. There are 5 components of human behavior: sensing and perception, working memory, cognition, motor behavior, and long-term memory. A model of a human task typically involves representing activity in most or all of these 5 areas. If this model is then executed or stimulated within a larger context such as a synthetic battlespace environment, then "stimuli" enter the model at the sensing and perception end of the model. Information and events flow back and forth through the other stages of the model; for example, information is stored into long-term memory from working memory and retrieved later from long-term memory. Eventually responses are generated that "flow" from the motor behavior end of the model back to the battle environment.

Several architectures and tools exist for building models of human behavior. Though these architectures vary widely in their modeling approach, they each address the five fundamental components of behavior in Figure 2. These applications can be grouped in the following three classes:

1) Finite-state machines, which employ decision trees,
2) Task network models, which represent sequential steps in a perception/decision process, and
3) Pure cognitive models, which are the most deeply rooted in psychological and organizational theory but tend to be highly complex and computationally intensive.

5. Related Efforts

Although these architectures are maturing via non-military venues, efforts are just beginning to apply this technology to military problems. The Air Force Research Laboratory (AFRL) Human Effectiveness Directorate at Wright Patterson AFB is pushing the state of the practice in collaboration with the Defense Modeling and Simulation Office (DMSO), the US Army, and a host of industry affiliates. Previous efforts from this Directorate include:

- The Combat Automation Requirements Testbed (CART) program, which is applying one of the many human performance modeling architectures to represent the decisions and tasks carried out by a strike aircraft pilot as the aircraft flies a strike mission [Martin, 2000], and

- The Agent-Based Modeling and Behavioral Representation (AMBR) program, which among other tasks is exploring the use of the High Level Architecture (HLA) as a means to improve the data interoperability of several existing human performance modeling architectures within a simulated battle [Young, 2000].

The key area that has yet to be directly addressed by previous efforts is the application of this technology to time-critical command and control decision-making processes. AFRL consider this an important next step in their research. In fact as of the writing of this paper, AFRL is sponsoring new human behavior modeling projects including an effort entitled "Cultural Modeling in C2." This ESC-based MITRE project team plans to stay in close contact with the AFRL-based projects, working in tandem with them to push the application of this technology into the C2 realm.

The ESC project team will also work in parallel with a sister project at MITRE entitled "Mental Models in Naturalistic Decision Making." This research project is in its second year of developing new methods for modeling cognitive competence [Burns, 2000].

6. Project Plans

The project team will develop and verify software surrogate prototypes addressing C2 mission areas. As stated previously, during the first year of the project the team will address the tasks performed at a Joint STARS operational console. This mission area will allow us to focus on individual operator perception and decision-making tasks for an initial C2 surrogate.

6.1 Technical Approach

We will begin by configuring a testbed for human behavior modeling methodologies and tools. This will involve (1) obtaining selected HBR modeling applications and battle simulations, and (2) establishing a computing facility for continued experimentation. Within this facility the project team will develop and experiment with a "JSTARS Operator Surrogate Human" (JOSH). The team will follow this process:

- ***Develop a preliminary software surrogate.*** This includes (1) performing a Cognitive Task Analysis (CTA) for the selected JSTARS operator C2 tasks, (2) choosing the best available architecture/toolset to model the set of C2 tasks identified in the CTA and using it to develop the software surrogate, and (3) choosing the best available battle simulation within which to exercise the software surrogate and performing the resulting interface design and development tasks.

- ***Implement a man-in-the-loop data collection program.*** This involves (1) identifying a man-in-the-loop console capability that addresses the selected human C2 tasks, (2) connecting this console to a battle simulation, preferably the same battle simulation chosen to "drive" the software surrogate, and (3) identifying operational experts to man the console and provide realistic human responses to selected battle scenarios. Alternately, the source for this data collection effort could be an existing military project studying related C2 operations (for example, JEFX, CAOC-X, or JSB).

- ***Perform iterative experimentation.*** This entails (1) selecting battle scenarios and performing baseline runs of these scenarios, (2) exercising the surrogate within these scenarios, (3) placing the human operator in the same scenarios, (4) comparing the surrogate's responses to the operator's responses, and (5) making adjustments to the software surrogate to more realistically represent operator responses. Figure 3, below, illustrates the three different environments that will be used to perform this experimentation.

- ***Evaluate and document the strengths and weaknesses of the prototype approach.*** This will include reporting on the utility of the software surrogate within the context of this experiment to (1) augment existing simulation capabilities and (2) represent humans-in-the-loop. Based on our experimentation we will also consider issues associated with using the surrogate in other contexts.

6.2 Experiment Configuration

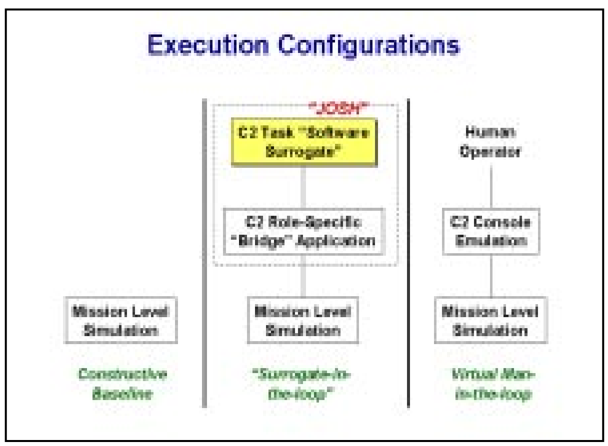

Figure 3: Execution Configurations

Figure 3 illustrates the computer application environments that will be employed to assess the capabilities of the JOSH. These are:

- ***Baseline (battle simulation only).*** This case is representative of a self-contained analysis or decision aid application.

- ***Man-in-the-loop.*** In this case a human C2 operator is manning his console, which is in turn interfaced to the battle simulation. In is analogous to a man-in-the-loop experiment or training application.

- ***Surrogate-in-the-loop.*** In this case a human behavioral model (in this case, the JOSH) is interfaced to the battle simulation instead of a human operator.

The objective is to assess, by comparing results across the three cases:

- how well the surrogate operator (JOSH) can improve on simulated C2 realism as compared with the baseline case (that is, assessing the surrogate's potential value for use in analysis and decision aid applications), and

- how well the surrogate can approximate the human operator's actions (assessing the surrogate's value in training and experimentation environments).

6.3 Preliminary Schedule

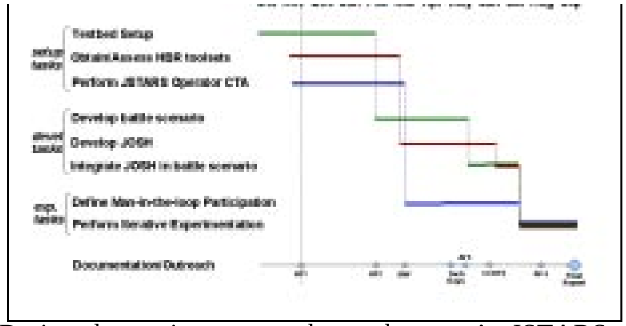

Figure 4: Preliminary Schedule

Figure 4 illustrates the tasks involved in the first year of the project and maps these tasks to project team skills. The tasks fall under three categories: project setup and preparation, prototype development, and experimentation. The timelines for each task are color-coded: red represents HBR engineering and model development work, blue represents mission area-specific (JSTARS) engineering and operator liaison work, and green represents general software/hardware infrastructure, battle simulation engineering, and simulation interface development.

During the project setup phase, the team's JSTARS engineer will work on an informal task analysis of the selected JSTARS Operator position while the simulation engineers populate the testbed facility and the HBR engineer assesses available modeling tools. This phase of the project is scheduled for completion in the February/March timeframe, at which point the JSTARS engineer will move on to planning the involvement of human operators in project experimentation. Meanwhile, the HBR engineer and simulation engineers will develop JOSH and the simulation environment that will provide the context for the experimentation. Finally during the last two months of the year the entire supports the experimentation phase.

7. Future Directions

After completing the first years' efforts, the team plans to address the more organizationally complex human behaviors involved in a collaborative team of C2 operators. The mission area for this work may be the team of operators on board the JSTARS aircraft or the time-critical targeting operations within an AOC. Another future project focus may be to explore how human behavior modeling can be employed to enhance ongoing attempts to simulate C2 using executable architectures. Decisions concerning future project focus areas will be made in conjunction with the progress and plans of related work being done by AFRL and industry affiliates. A strategy developed in collaboration with these partners will help the collective resources of the projects make the most progress modeling human behavior across a variety of C2 mission areas.

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Author Biography

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