Capturing Behavioral Influences in Synthetic C2:
What We've Learned So Far and Where We Need to Go

Charles D. Bowen
Ronald G. Couture
R. Douglas Flournoy
Eric M. Forbell
C. Donald Means
The MITRE Corporation
202 Burlington Road
Bedford, MA 01730
781-271-4970
(bdc, rcouture, rflourno, eforbell, donmeans)@mitre.org

Keywords:
Human Behavior Modeling, C2, Joint STARS, Simulation Based Acquisition

ABSTRACT: *The MITRE Corporation in Bedford, MA is executing a small research project entitled "Capturing Behavioral Influences in Synthetic C2." This project is being sponsored by the Air Force Electronic Systems Center (ESC) and began in November of 2001. At the previous SIW we presented the project plan. This paper presents initial findings from the project based on preliminary prototyping efforts and a review of related work in the community.*

We originally set out to "start simple" by modeling a single C2 operator in the Joint Surveillance and Target Attack Radar System (JSTARS) mission area; however, we found it both undesirable and infeasible to single out a single operator since C2 at its core is collaborative teamwork. C2 modeling efforts need to focus on team or unit-level models. To make better use of limited available behavior data, C2 behavior modeling efforts must expand on existing information processing models and address specific taxonomies of C2 user tasks. Hybrid models may be necessary to bring the best of multiple modeling approaches to bear on the complex nature of C2 team/unit modeling. Guidelines are needed to (1) better define appropriate levels of detail/investment in, and (2) provide validation approaches for, behavior modeling across the different C2 application areas. Finally, in efforts to interface interactive human behavior models with battle simulations, it is necessary to understand and refine the "hooks" that enable the behavior models to appropriately impact the simulated battle.

1. Introduction

This paper provides initial findings from, and a proposed path forward for, a behavior modeling project effort that started in November 2001. 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). The purpose of the project is to explore application of emerging behavioral modeling techniques within military simulations to better capture the cognitive and organizational factors that influence C2 operations [Flournoy, 2002].

This paper begins with a background section that describes 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 progress on the project in FY02 is provided in Section 3. This leads into sections that detail our lessons learned on the two facets of the project: (1) developing the JSTARS Operator Surrogate Human (JOSH) (Section 4), and (2) exploring the potential for connecting JOSH to a battle simulation to "play" a JSTARS mission within a larger battle context (Section 5). Based on these lessons learned, we outline a path forward for the work in Section 6. Finally in Section 7 we state the potential impact of this work in collaboration with government and industry partner projects as we each strive for *comprehensive yet cost-effective* approaches to building and applying behavior-centric models of C2.

2. Background

We began this research thrust in FY02, citing a National Research Council (NRC) study commonly referred to as the "Green Book" (pictured below) that put forth recommendations to improve human behavior representation in military simulations [NRC, 1998]. Indeed on a local level at ESC we recognized that the representation of decision-making behaviors in our C2 simulations did not begin to match our well-developed models of the more physical aspects of C2 (for example, communication channels and sensor performance). While other DoD research organizations have invested heavily in behavior modeling for many years—including AFRL, the Army Modeling and Simulation Office (AMSO), the Defense Modeling and Simulation Office (DMSO), and the Office of Naval Research (ONR)—our MOIE effort in FY02 marked ESC's initial entry in the field. Continued ESC investment in behavior modeling approaches is now critical with the emergence of new C2 initiatives such as the Multi-mission C2 Aircraft (MC2A) and the Air Operations Center (AOC) Time Critical Targeting (TCT) Cell. These initiatives rely on teams of C2 operators dealing with increased information flow under reduced manpower and footprint conditions. Modeling the behavior of such teams is key to determining how advanced systems and operational concepts can best be employed to assist them.

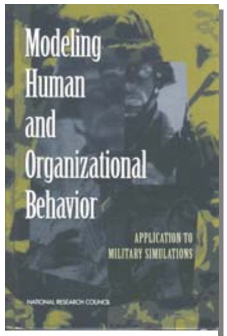

Figure 1. The "Green Book"

Figure 2 illustrates a process for leveraging behavior models to augment C2 behaviors in battle simulations. First, a task analysis is undertaken to determine roles/responsibilities and the associated behaviors of the subject warfighter or team of warfighters. Then, these behaviors are entered into a behavior modeling tool to produce an standalone executable behavior model. Finally, this executable behavior model is interfaced to a battle simulation so that it receives situational updates from the simulation and responds with decisions that effect the progress of the battle in the simulation. Note the dual-headed arrows between each step in the process: although the desired flow of the process proceeds from left to right in the diagram, in practice the process is iterative in nature. The capabilities of the behavior modeling tool dictate to some extent the level and focus of the task analysis. Similarly, the nature of the selected battle simulation influences the design of the executable behavior model.

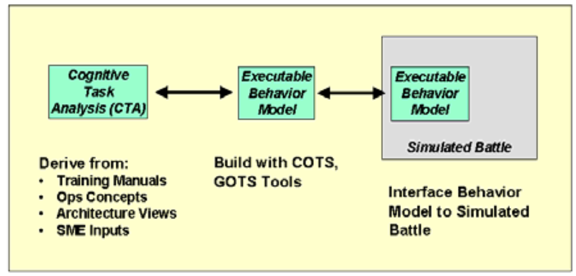

Figure 2. A Process for Capturing Behavioral Influences in Synthetic C2.

3. Overview of FY02 Progress

We began the research effort last year by first assessing the C2 modeling potential of available behavior modeling tools and battle simulations. Based on these findings we developed an initial prototype of the Joint STARS Operator Surrogate Human (JOSH) C2 behavior model using the AFRL-sponsored Crew Automation Requirements Testbed (CART) modeling tool [Martin, 2000]. We selected CART over other behavior modeling tools for our initial prototyping efforts because of these perceived capabilities:

- Task-network approach and mature graphical user interface (GUI) for creating an initial model from task analysis results,
- Goals & ability to encode overarching effects,
- Workload estimation based on validated research,
- HLA interface, and
- Successful history on AFRL project work.

While developing the JOSH C2 behavior model using CART, we selected and installed a set of applications to form the basis for a simulated battle testbed for CART. For our primary battle simulation we considered the Extended Air Defense Simulation (EADSIM) and the Joint Interim Mission Model (JIMM). Both of these mission-level simulations have achieved a high level of acceptance at ESC across a variety of analysis and experimentation projects. We selected EADSIM for our initial research efforts on the strength of (1) its strong reputation for modeling the physical aspects of C2, and (2) its straightforward GUI for facilitating battle scenario development.

We federated the Joint STARS Transportable Emulator (JSTE) with EADSIM in order to provide (1) a JSTARS human-in-the-loop console and (2) JSTARS sensor output information for the testbed. Finally, we federated the Integrated Target Environment Simulation Tool (ITEST) with EADSIM and the JSTE to provide additional ground vehicle traffic if necessary to create a realistic environment for JOSH.

4. Lessons Learned Using CART to Build JOSH

Figure 3, below, provides a high-level overview of our findings from our initial FY02 efforts, and based on these findings, potential focus areas for further research in FY03. The remaining text in this section and in Section 5 details the project experiences that led to these findings. Then in Section 6, a plan is presented for addressing some of the proposed focus areas.

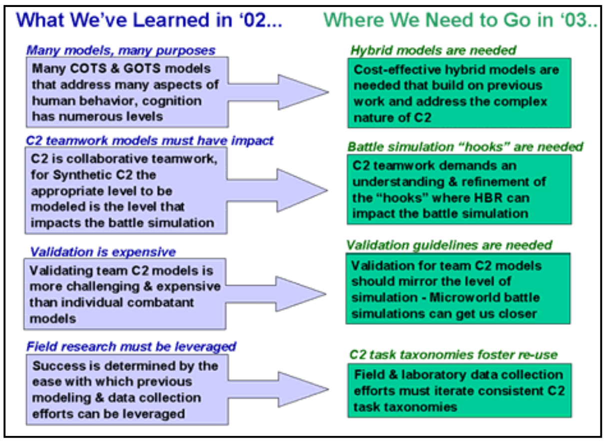

Figure 3. Overview of Initial Findings and Focus Areas for Future Research

Our tailored Cognitive Task Analysis (CTA) techniques were key to successfully representing operator roles and responsibilities in JOSH. We leveraged CART's well-designed user interface and task-network modeling approach to quickly construct a first-order version of JOSH and proceed through several evaluation and refinement spirals of JOSH.

One of our first JOSH spirals involved raising the level of authority of the roles and responsibilities modeled in JOSH so that its decisions could impact events in a larger simulated battle context and be more compatible with existing battlespace environments such as EADSIM. Initially intended to be focused on a single position within the operations section of the Joint STARS aircraft, we recognized a need to expand JOSH to cover the effect of the entire Joint STARS operations team on the battle by refocusing on the Senior Director (team leader) position with additional tasks included to cover many of the other team members' roles. Concurrent with our first year efforts, the Human Effectiveness Directorate of AFRL began using CART to model Air Operations Center (AOC) activities. For reasons similar to ours in focusing on the Senior Director position for Joint STARS, AFRL has also chosen to focus their AOC ISR Management model on the team leader position.

Although CART and the other behavior modeling tools we examined showed much promise, none alone offered all the key elements necessary to bring behavior modeling technology to bear on the C2 simulation needs of our ESC sponsors. Each of the tools lacked either (1) the cognitive functionality to represent key Joint STARS tasks (for example, elevating the status of a nominated track to a time-critical target), or (2) the user interface maturity necessary for cost-effective application by other than the developers of the tool. In addition, support to interfacing these tools to an external simulated battle, and thereby realizing their potential to enhance a variety of C2 simulation use cases, was rudimentary at best.

In addition to experimenting with JOSH in the lab, we developed several technical working alliances with related government and industry teams. As we shared knowledge with these teams and others from the growing DoD behavior modeling "community-at-large," we found that the above challenges we identified last year were echoed frequently by others as crucial hurdles to overcome via additional research and development.

5. Lessons Learned Toward Running JOSH within a Simulated Battle

In working to connect our EADSIM/JSTE/ITEST federation to the CART-based JOSH model, we identified several technical hurdles that we needed to cross to achieve a working interface to JOSH:

- **Our behavior model needed to focus on a team leader (management/decision maker) to impact the battle in EADSIM.** As a result of this finding, as discussed in Section 4, we refocused our JOSH model on the JSTARS Senior Director role; however, that committed us to additional algorithmic or behavior modeling work to model the information inputs of the team members to the Senior Director to feed his decisions.
- **EADSIM Version Release Issues.** The planned release of Version 10 of EADSIM, which contained the capability to process tracks from external sources (e.g., JOSH), was delayed until we were three-quarters through our initial year of research.
- **CART HLA Interface Limitations.** The version of CART we worked with was limited to operating in only Real-time Platform Reference (RPR) Federation Object Model (FOM) federations, and implemented only a small part of this FOM in its interface. If a flexible-FOM HLA "front end" is

implemented in CART in the future, this would considerably ease attempts to federate CART-based models with battle simulations. We feel this is a worthy target for funding in the future, as a more flexible data interface would make this already promising tool even more attractive to a broad user-base of military behavior simulators.

Because of the challenges we faced interfacing our EADSIM/JSTE/ITEST federation with JOSH, we began exploring the option of using a MITRE-developed C2 microworld as our testbed for JOSH. This microworld was initially developed under the name "Friends or Foes" for the CAFC2S project *Mental Models in Naturalistic Decision Making* [Burns, 2000]. This microworld approach provides complete access to source code; and with that, streamlines many of the testbed support tasks necessary for the research project. During initial risk-assessment prototyping efforts with this microworld we were pleasantly surprised with the leap we experienced in (1) interface flexibility, (2) ease of incorporating critical scenario development capabilities, and (3) ease of developing operator cueing and data collection capabilities to better support JOSH experimentation.

6. Path Forward

We seek to extend our research to a second year that will address key challenges in C2 behavior modeling by pioneering cost-effective methods for applying and re-using state-of-the-art human behavior representation (HBR) and data exchange techniques. The work will focus on the extension of JOSH to incorporate hybrid modeling techniques. We will experiment with these techniques within our flexible C2 microworld battle environment. By following this approach we will also learn lessons regarding data exchange techniques that can bridge human behavior modeling tools with one another and with battle simulations at runtime. We will continue to draw on interdisciplinary resources across MITRE and technical working alliances across the research community by examining the results of AOC Cognitive Task Analyses (MITRE-Bedford) and AOC and MC2A modeling efforts (AFRL, Lincoln Labs/Aptima) for our research.

The text below in Sections 6.1 and 6.2 details our proposed technical approach and anticipated products, respectively.

6.1 Technical Approach

Here is a detailed outline of our proposed approach:

- **Extend JOSH to incorporate hybrid modeling techniques that better address C2 cognitive functions and team or unit behavior**.
  - **(1)** Examine the cost-effective feasibility of several promising models that were identified in the first year of this effort (e.g., ACT-R, SOAR, etc.).
  - **(2)** Model key cognitive functions with selected tools to supplement existing behavior modeling.
  - **(3)** Construct data exchange "bridges" to link the existing surrogate behavior model to the new cognitive models.

- **Expand on the existing C2 microworld battle simulation to serve as a testbed for hybrid model refinement and data exchange techniques.**
  - **(1)** Evolve the previously developed C2 microworld (Friends or Foes) to interact with the desired versions of JOSH.
  - **(2)** Establish cueing and data collection in the C2 microworld to support collection of human operator behaviors.
  - **(3)** Examine protocols to standardize data exchange between human behavior models and microworlds/battle simulations, and providing guidance and requirements to battle simulation developers regarding the "hooks" where HBR can make a difference.

- **Examine the cost-effectiveness of supplementing the current Joint STARS software surrogate to better represent generic C2 (AOC, MC2A, and TCT) modeling efforts.**
  - **(1)** Analyze the emergent AOC and MC2A human behavior modeling efforts (e.g., AFRL, Lincoln Labs/Aptima) for re-use potential.
  - **(2)** Review cognitive task analysis efforts from within the MITRE Center for Air Force C2 Systems (CAFC2S) for consistent taxonomy and applicability.
  - **(3)** Examine the cost-effectiveness of supplementing the existing JOSH with a more refined AOC model that better represent AOC cognitive decision making tasks.

6.2 Products

Our goal will be to provide the following products as a result of next years' efforts:

- JOSH v2 operating in Microworld environment
- Papers summarizing lessons learned from:
  - **(1)** hybrid modeling investigation,
  - **(2)** Microworld-to-Behavior Model interface efforts, and
  - **(3)** cost-effectiveness analyses.

7. Impact and Technology Transition Opportunities

With expertise in C2 systems and operations, simulation interoperability, and human performance modeling, the MITRE team is looking to continue to bring this interdisciplinary team to bear on applications of human performance modeling methods in synthetic C2. Coming efforts on the project will impact these three main areas:

- ***Educated investment in C2 behavior modeling.*** By targeting key challenges faced by this project last year and echoed by our industry and government partners, this effort promotes (1) increasing technical quality and (2) reducing the costs associated with applying behavior models in C2 simulation efforts.

- ***Enhanced realism in simulated C2.*** The work has potential to enhance the realism of simulated battles at key human perception and decision-making points. These can realize useful metrics in the struggle to decrease footprint and maintain effectiveness. This promises to improve the quality of simulation support in several application areas including analysis and experimentation. Programs likely to benefit from the work include MC2A/MC2C and TCT Cell efforts. For example, within the MC2A, the crew may be called upon to perform ground and air surveillance tasks, cover various ISR management tasks (possibly extending to space-based radar and UAV control) and serve as an AOC execution cell. Team roles and responsibilities must be carefully designed for maximum effectiveness and flexibility to meet these lofty objectives; likewise, computer systems must support this flexibility. We believe the lessons learned from this MOIE have great potential to contribute to addressing these MC2A challenges. From a mission-area standpoint, our growing Joint STARS expertise coupled with AFRL's AOC work and the work of Aptima, Inc. in AWACS team design form a powerful base for collaboration toward an MC2A analysis capability.

- ***Influencing the state-of-the-practice in the community-at-large.*** Having established relationships with several related government and industry project teams last year, we are now in a position to share findings, provide recommendations, and influence standards development.

While acknowledging the challenge of constructing models that capture the cognitive complexities of team behavior, we have made substantial progress and seek to continue our focus on cost-effective reuse of state-of-the-art behavior modeling efforts that impact synthetic command and control.

References

[NRC, 1998] National Research Council Panel on Modeling Human Behavior and Command Decision Making: Representations for Military Simulations. *Modeling Human and Organizational Behavior: Application to Military Simulations,* National Academy Press, 1998.

[Martin, 2000] Dr. Edward Martin. *Tools for Including Realistic Representations of Operator Performance in DoD Constructive Simulations*, AFRL Human Effectiveness Directorate, 2000.

[Burns, 2000] Kevin Burns. *Mental Models in Naturalistic Decision Making: A Proposal for MITRE-Sponsored Research*, the MITRE Corporation, July 2000.

[Flournoy, 2002] R. Douglas Flournoy. *Leveraging Human Behavior Modeling Technologies to Strengthen Simulation-Based C2 System Acquisition*, The MITRE Corporation, March 2002.

Author Biographies

CHARLES D. "CHIP" BOWEN is a Lead Engineer for The MITRE Corporation's CAFC2S in Bedford, Massachusetts. Chip's area of expertise is human computer interaction and user-centered software design and evaluation. His experience spans the major phases of the lifecycle design process and includes military, air traffic control, and electrical power plant domains. He is currently exploring the utility as well as the usability of human behavior modeling methods and tools for enhancing the simulation of C2 systems. He also serves as a systems engineer supporting the Joint STARS program office at Hanscom AFB in Lexington, Massachusetts. Chip has an MS in Applied Experimental Psychology from Rensselaer Polytechnic Institute in Troy, NY and a BA in Psychology from State University of New York College at Geneseo, NY.

RONALD G. COUTURE is a Lead Software Systems Engineer in the Air Force Center at MITRE. His responsibilities on this research project involved the integration of components needed for the model to participate in a simulation. While at MITRE, he has worked on numerous strategic systems for the Department of Defense. Mr. Couture holds a Bachelor of Science degree in Electrical Engineering from the University of Massachusetts and a Masters of Science

Degree in Electrical Engineering from Virginia Tech.

R. DOUGLAS FLOURNOY is a Principal Simulation and Modeling Engineer and Associate Section Leader for The MITRE CAFC2S in Bedford, Massachusetts. He is currently investigating the utility of human behavior modeling methods and tools for enhancing the simulation of C2 systems. He also serves as a simulation interoperability engineer supporting ESC/CXC on the Hanscom AFB in nearby Lexington, Massachusetts. Previously he investigated methods for providing simulation interfaces to Air Force Command and Control systems, and developed user interface and algorithmic software prototypes for MITRE's Center for Advanced Aviation System Development (CAASD). Mr. Flournoy holds a Bachelor of Science Degree in Mechanical Engineering from the Pennsylvania State University and a Master of Science Degree in Operations Research from the George Washington University.

ERIC M. FORBELL is a Senior Research Engineer at the MITRE Corporation in Bedford, Massachusetts. At MITRE, he specializes in rapidly building prototype software for research purposes. Currently he is working on a lightweight, distributed simulation of a C2 battlespace that will support the plug-and-play of human and artificial operators. His other interests include computational cognitive modeling, simulation, machine learning, and understanding symbol processing at a neural level. Mr. Forbell attended Bowdoin College where he received a Bachelor of Arts in both Computer Science and Neuroscience.

C. DONALD MEANS is an Information Systems Engineer for the MITRE CAFC2S in Bedford, Massachusetts. Mr. Means holds a Bachelor of Science Degree in Psychology from Bradley University and has completed his coursework for a Master of Arts Degree in Experimental Psychology and Human Factors from the University of Dayton. He is currently developing JOSH, a behavior model of a JSTARS operator, using the CART behavior modeling tool. He has also investigated several other behavior modeling tools focusing on their utility to C2 modeling. In addition, he has experience ranging from conducting a Cognitive Task Analysis for Time Critical Targeting, performing heuristic evaluations of different Air Force C2 systems, and developing web pages/portals for the Air Force.