Assessing Enhanced Command and Control Technologies Through Modeling and Simulation

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Abstract

Advanced command and control technologies offer significant enhancements to our ability to perform at the tempo required by modern day crisis operations. Unfortunately, each of these technologies focuses on a relatively limited functional and organizational segment within the command and control structure but the impact of the changes brought about by the incorporation of the technology can extend beyond the focus area.

How do military decision makers (the users of the technologies) and the procurement agencies assess the impact of proposed changes to command and control structures. Some have suggested that a new breed of modeling and simulation tools could provide the answers.

1 The Problem

There are no simulations currently available that focus on the dynamic interactions and decision processes that comprise the military command and control environment. One of the fundamental reasons for the lack of command and control simulations stems from the fact that command and control is a complex, nonlinear system of systems. "Nonlinearity, which covers such concepts as chaos theory and complexity theory, does not conform to those qualities found in linearity. It is not proportional, additive, or replicable, and the demonstratability of cause and effects are ambiguous."[1] These factors represent a profound problem for the designers and developers of traditional simulation environments characterized by predictable, deterministic models of the world. The issue then becomes to identify the key elements needed for a command and control simulation environment and what methodology identifies, describes, and develops models with these elements.

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[1] Czerwinski, Tom, Coping with Bounds: Speculations on Nonlinearity in Military Affairs, CCRP May 1998

2 Relevance of the Proposed Paper to the Command and Control Environment

The paper will address the role of modeling and simulation tools in assessing command and control enhancements stemming from the introduction of advanced technology components. Partially based on experience gained in designing and developing the Air Operations Enterprise Model for the Defense Advanced Research Projects Agency's (DARPA's) "Agile Control of Military Forces" project the author will explore the role for modeling and simulation in command and control assessments. They will discuss the requirements for an adequate simulation environment for command and control assessment and highlight ways that the utility of these tools can extend beyond the laboratory walls to support active decision making.

3 Analyzing Command and Control Systems

There appears to be a growing chasm between our need to describe, understand, and model the real world of military command and control and the capabilities of various analytical methods to support this requirement. An underlying reason for this is the fact that most people are uncomfortable with complexity and its associated uncertainty as part of an analytical process. The most common method for analyzing complex systems is through decomposition. Decomposition attempts to beak the system into recognizable, manageable, components that provide an increased level of predictability.

Analytical tools such as IDEF are often used to decompose a single command and control process into its individual steps. These tools typically characterize the process into a linear model with inputs, controls, and mechanisms coming together as part of a planned set of actions to produce a product. It is not surprising since these methodologies had their origins in the manufacturing environment as a tool to improve assembly line productivity. The success of these tools in this role prompted some to look at additional applications. The search began to identify candidate products and their associated processes for decomposition, modeling and streamlining through reengineering.

4 Modeling and Simulation in the Command and Control Environment

There are several reasons for developing simulations of the command and control environment. Detailed simulations, and their associated models, support process improvement through reengineering and the development of new technologies. These models and simulations tend to be more focused in terms of their scope. They typically cover a single process (i.e. Time Critical Targeting, ATO Generation) but they cover this process in detail. These models and simulations also tend to focus on a product or what the process under analysis produces. Their primary purpose is to understand the inner logic and decision process in order to improve the quality and/or timeliness of the product.

There is a second group of reasons for command and control simulations. Training the human operators through "human in the loop" simulation environments offers the potential for greater flexibility and depth of training because the simulated environments can be configured to reflect the broad scope of possible military operations. The simulation environment also provides the opportunity for training in large-scale operations that is impossible to duplicate in the current exercise environment. The use of simulations to support human in the loop training tends to be specialized with a single simulation supporting only one node in the command and control environment.

In addition to supporting training, simulations of the command and control environment can assist in assessing the impact of the introduction of new technologies or procedures into a part of the environment. For example, a new technology seeks to eliminate the twenty-four hour ATO cycle. Now, taskings flow from the Air Operations Center to the wings in a nearly continuous stream. The tasking process improves, but what is the impact on the wing in terms of aircrew and aircraft management? There may be additional requirements for status reports from both the intelligence staff and the wings to provide frequent input to the new technology. The issue becomes, do the benefits of the new process or technology outweigh the cost in terms of destabilization elsewhere in the command and control system. Again, without a simulation environment representing the entire command and control system to support assessment across the full range of potential operations these problems may not surface until a crisis occurs.

The final area where these macro-level simulations can assist is by facilitating the study and analysis of potential improvements from a broader perspective. The identified need to support sensor-to-shooter concepts to improve the speed and responsiveness of command necessitates a mush broader perspective encompassing several of the detailed processes into a system level improvement.

4.1 Views of the Command and Control Environment

Command and Control analysis takes one of two perspectives. The first is the micro-level view supported by IDEF modeling methodologies. The second is a macro-level view. This approach is not currently supported by a wide variety of tools however; it is possible to combine various tools and techniques to support this level of analysis.

Micro-analysis of the command and control environment is characterized by decomposition and a product focus. For example, the air operations process is broken down into the Air tasking Order (ATO) Production Process or the Time Critical targeting Process. The process typically begins with a "Top Level (Level 0) Model that has one activity box surrounded by a multitude of inputs, controls, mechanisms and outputs. This single box representation of a complex process is then systematically decomposed into a set of activities that closely resemble manufacturing production. In the case of the ATO, the view typically is from a single perspective with the ATO progressing through an assembly line type process until a finished product emerges from the right hand side. It is a linear process with limited feedback loops. What's more, the process assumes that there is a stream of these ATOs progressing down the assembly line following some predefined schedule.

The micro-level analysis is a very good tool for fine-tuning a single process or, as a road map for developing technology. For example, there are a number of research and development efforts currently underway to examine methods to speed up the ATO development process.

The micro-level view does not support the development of modeling and simulation tools for the command and control environment because it hides the complexity as a series of "off chart" connectors.

Modeling and simulation of the command and control environment requires a macro-level approach that focuses on how activities are accomplished rather than what the command and control system produces. In this macro-level view the individual processes, so carefully modeled in the micro-view, are represented as a black box. Yes, it is important to know that the sub-processes are occurring but the more critical element of the macro-view is the complex network of interactions that support the entire process.

Interactions among the various nodes in the command and control system are only referenced in the abstract in most IDEF style drawings. One has to carefully examine the activity diagrams to identify all of the relevant "off page" connectors. The problem is that these only represent a small fraction of the interactions taking place in the environment.

4.2 Components of Macro Level Models

Models and simulations supporting command and control assessment have three basic components. There is the physical world where actual instruments (aircraft, tanks, ships, battalions, squadrons, task groups) of military operations reside move and engage other objects. There is the communication layer that provides a representation of the communications channels available to support command and control and, there is the cognitive layer that represents military decision makers, their staff organizations (in fact a different layer of decision makers) and the information flows linking these elements. It should also be evident from the examples given above that; the cognitive elements often coexist with the actual instruments.

The three levels of model entities described above are critical for effective representation of command and control. Command and control systems function through a constant flow of information. The information object representing the real world event and not the event itself drives command and control processes. Command and Control models and simulations therefore, need effective strategies and design concepts to draw a clear distinction between fact and perceptions.

C2 models and simulations also need to deal with roles and responsibilities of the various nodes in the system. Behavior representation of the staff, which is often rule driven is also a critical element. This behavior representation tends to be formalized and rules based when applied to an organizational entity. This differs from the behavior representation of individuals that tends to be more flexible in its response to external stimuli. The distinction between rules based organizational behavior, the free form behavior of individuals facilitates the definition, and development of rules based behavior models for the various command and control entities in that simulation environment. Each node also requires a dynamic method for demoting ownership since ownership and location identify the communications elements used to support interactions.

The simulation environment also needs to incorporate structures for representing tasks, processes, and work flows. These representations should be rich enough to allow some flexibility as the organization interacts with the environment and not just a reflection of task duration. From the macro-level perspective, the individual activities and processes that represent command and control are important in that they represent the cyclical workload of the various nodes in the system. Cycle times and workload are important elements obtained from the micro-level analysis. At the macro-level, the cycle times of all the processes performed at a single node, plotted on a timeline, helps to identify task conflicts and overwork conditions. Activity descriptions also include all the possible triggering mechanisms.

5 Developing Macro Level C2 Simulations

The development strategies for macro-level command and control simulations differ from the micro-level models and simulations in several important ways. First, macro-level simulations must be composable. That is, individual simulation components are turned off and on (normally at initialization) to support various combinations of human in the loop training or to be replaced by the representation of new technology components. Composability also means that the models have to be designed with recognizable independent components.

Macro-level simulations also require examination of individual processes from a different perspective. While the actual activities remain important, macro-level models need to address the issues of activity contention, prioritization, and activity behavior during a suspended state (referred to as process aging). Macro-level simulations are not concerned with improving an individual but with reflecting the overall command and control environment. Interactions, especially those that occur when there are problems are very important. Finally, macro-level simulations will evolve continuously. They are learning aids that help the human explore and understand the command and control process. Interactions will change over time to reflect the parallel evolution of the actual command and control system.

5.1 Composable Design Strategy

A key requirement for macro-level C2 simulations is composability. That is, the ability to support a variety of configurations either at initialization or dynamically during a run.

Composability starts with the design concept. Developers need to assess the purpose of the simulation. The purpose will help define critical elements; important elements, necessary elements and nice-to have elements for the simulation. The next step in the process is to define the individual simulation components representing the node of the command and control system. For the AOEM, a product based decomposition proved effective. Each component of the simulation produced a single information object. The component then delivered the product to its customers via the appropriate communications channel.

Component attributes included the identification, affiliation (blue, red, neutral), parent entity, communications methods available for internal and external communications, geographic location, and simulation component status (internal, external). Work was begun on developing a modeling mark-up language (MML) to provide users of the simulation with an easy to use interface that provided full freedom to activate, deactivate individual components, to change ownership (used to explore alternative command and control organizational structures) and communications channels (to reflect changes to communications capabilities). The MML was never fully implemented even though the language constructs were completed due to the lack of immediate need in the project. One of the issues left unresolved was the matter of consistency checking to support composability. A composable simulation needs a mechanism to ensure that the selected configuration is complete and that all inputs and outputs are provided and correctly routed.

5.2 A Hybrid Methodology for Macro-Level Model and Simulation Development

These requirements lead to the need to develop a hybrid approach, incorporating elements of the micro-level analytical process along with additional methodologies to support command and control simulations.

The AOEM development team employed a Multi-Perspective Modeling Framework[2] that provided three critical components of the command and control system model. These components were:

- Business Model to describe the concepts and processes that are used in the context of the command and control domain (Air Operations) being studied
- Role, Activity and Communications Model to identify the actors involved and the interactions between them
- Meta-Model to provide a taxonomic structure capturing all concepts that are important to the air operation.

5.2.1 Scenario Based Approach to Model Development

The critical command and control system characteristics are not usually captured during activity analysis. Discovery of these characteristics requires a systematic analysis of both the activities and responsibilities. The best methodology for uncovering these factors is through a scenario based analysis process.

The AOEM team developed and refined a scenario template approach to uncover these factors. The scenario template approach begins with an analysis of existing process models and descriptions. From these, the team constructs a model

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[2] Yun-Heh Chen-Burger, A Knowledge based Multi-Perspective Framework for Enterprise Modeling, Feb 2001, Artificial Intelligence Applications Institute, University of Edinburgh

of the system node being analyzed. A scenario is developed to place the activities into context and to attempt to create situations where the actor in the node is faced with competing priorities. Domain experts then assist the team in a scenario walk through. At each step in the scenario the domain experts are asked to describe the relative priority assigned each activity and to assess the workflow described in the scenario context. The act of refining the scenario to improve realism helps to build a sense of ownership and improve participation during subsequent analysis. The initial walk through is conducted following the textbook description. This is the first scenario template.

Following completion of the first template, the team begins the process again. This time, the domain experts are asked, “What can go wrong here?” The teams experience is that the first answer is the typical “It depends.” This is followed with further questions to identify the three most likely “it depends” factors. The walkthrough is repeated, injecting each of the three factors and the domain experts walk through a typical response. Each of these cases becomes a scenario template for the modeling team.

These templates begin to answer important questions regarding the interactions that take place in the command and control system. Some of the interactions reflect the formal organizational relationships but, quite often, the informal interaction network begins to emerge. Both of these interaction networks are critical in command and control modeling. For example, the re-tasking of a mission to attack a time critical target is performed at the CRC level. The decision is transmitted to the appropriate mission commander and the pilots execute the mission. What other actions can be triggered by this single action. What happens when the re-tasking changes the requirements for the aerial tanker, which then cannot support later missions? When does current operations discover that the scheduled target will not be struck on time? Does combat ops re-task a future mission or turn the target back to combat plans for future scheduling? All of these are possible consequences of the time critical targeting decision and each in turn, can trigger other events. If the impact is significant, the entire command and control system can become unstable and chaos could ensue. The ability to see this potential and to focus on developing strategies, procedures, and technologies to counter this system wide behavior is the primary role of modeling and simulation support for command and control analysis.

5.2.2 Business Model Development

The business model used to support the development of the Air Operations Enterprise Model originated with the IDEF diagrams prepared to support Business Process Reengineering by the Air Force. The team quickly discovered that these representations of the command and control process were incomplete and lacked essential elements of information.

The IDEF models analyzed processes from a single "process owner" perspective therefore interactions with other organizations were treated as external connections. This single process view fails to address issues such as workload, activity priority, activity interruptability, and activity aging. Humans can multi-task. A person can watch television while talking on the phone with attention resources switching dynamically from one process to another. The same holds true for a pilot in an aircraft. She monitors system performance, maintains course, speed and altitude, and communicates with various ground and airborne agencies. These are parallel tasks. In the command post environment, staff officers often work multiple issues simultaneously. The issue from a modeling and simulation perspective is to accurately reflect the relative priority assigned to each activity and then to mimic the shift in resource allocation as the workload exceeds capability.

5.2.3 Role Responsibility and Communications Modeling

Each node in the command and control system is responsible for a set of goals. It achieves these goals through a plan composed of a set of defined activities. The relative priorities among the assigned activities are constantly shifting in response to schedule cycles and unanticipated interruptions. Preparing routine reports is often delayed while responding to the general's request for information. Preparing the report can be interrupted and later resumed. Not all activities are interruptible and many activities build a certain level of inertia as they progress. This inertia makes it more difficult to displace an activity in progress unless there is a significantly higher priority. For example, a pilot trying to avoid a surface to air missile will probably not respond to a request for information until the danger has passed or, responding to a request may be delayed until a course change is executed.

The issue of interruptability identified a key characteristic of the activities performed by the command and control node. One of the simulation metrics for measuring the impact of new technology measured the relative amount of proactive and reactive behavior at each node. Proactive behavior represented those activities that directly contributed to the node achieving its goal through a systematic plan. Reactive behavior occurred when an external event caused the node to deviate from its planned activity to perform another activity. By measuring the percentage of time that an individual node engaged in proactive vs. reactive behavior both before and after the introduction of a controlled change we were able to identify command and control nodes that were impacted by the change. Often, these nodes were only remotely connected (through many intermediate nodes) to the node where the change was implemented. Another factor affecting the measurement of behavior types was that a single activity could be proactive or reactive based on the triggering event? This factor requires a C2 simulation environment to accurately capture both the triggering event and the ensuing activity.

An additional issue for the model and simulation developer is to reflect the aging process that occurs as the activity sits in a suspended state. Many tasks can be picked up right were they were after a brief suspension. A longer time in a suspended state often results in abandoning the activity and reinitializing.

6 Conclusion and Recommendations for the Future

Recent decisions to treat command and control as a weapon system will increase the need to develop a family of simulation environments to support analysis, assessment, and human in the loop training. The problem is that development of command and control simulations is time consuming and there are few standards available to provide a common basis for model development. Command and control simulation developers need a forum to discuss the various aspects of developing these macro-level simulations and to begin to define a set of standards that will support future interoperability.

These standards must evolve over time based on proven methods and representations. The open forum, where developers and users of command and control simulations exchange ideas, is critical for the broad testing of design concepts, methodologies, and interface specifications.

C2 simulation development is, and will continue to be an evolving, interactive process that is only as good as the level of participation from both the development and user community. These simulations will not be the Holy Grail for command and control. They will not provide definitive answers but will help to develop insight into and understanding of command and control as a system of systems.