Proceedings of the 2002 Winter Simulation Conference
E. Yücesan, C.-H. Chen, J. L. Snowdon, and J. M. Charnes, eds.

THE USE OF AGENT-BASED MODELS IN MILITARY CONCEPT DEVELOPMENT

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ABSTRACT

Modeling and simulation of military operational concepts has historically been exceedingly difficult and costly. This is in part due to the inherent complexity of military operations. This paper discusses a method of analysis, Agent-Based Modeling, which brings an appropriate level of complexity to the task of evaluating military operational concepts. Techniques for military concept development are addressed and a potential case study is presented.

1 INTRODUCTION

One of the key problems in military concept development is that military domains are ultra-dimensional, confounding attempts to appropriately represent every important facet with mathematical models or simulations. One of the central questions about appropriate representation is how to provide enough detail in a military model or simulation without overwhelming the user (or the computer) with inputs and scenario dependencies. For example, a particular scenario may need to take into account the existence of distributed platforms, supply levels, availability and reliability of equipment, availability of personnel, weather, terrain, enemy activity, and other important aspects. Moreover, delays and losses must be considered. Models of military scenarios using traditional methods can quickly get bogged down in the minutiae of the battle, yet aggregation of the processes often does not provide enough detail to examine important dynamics in combat processes. Traditional modeling methods are vestiges of Industrial Age processes and even more poorly represent concepts for future networked warfare.

1.1 Agent-Based Modeling

This paper discusses the use of a new tool for military concept development, Agent-Based Models. In agent-based modeling, complex, real-world systems are modeled as collections of autonomous decision-making entities, called agents. Each agent individually assesses its situation and makes decisions based upon its own set of rules. Agents may execute various behaviors appropriate for the system they represent – for example, sensing, maneuvering, or engaging. Repetitive, competitive interactions between agents are a feature of agent-based modeling, which relies on the power of computers to explore dynamics out of reach of pure mathematical methods.

Model simulations are run hundreds or thousands of times to generate a distribution of behavior, and behavior is compared with historical data to ensure that the model is correctly calibrated. ABM results in a realistic simulation of a system because it emulates the manner in which the world really operates. Even a simple model can exhibit complex behavior patterns and provide valuable information about the dynamics of the real world. Agents are capable of evolving, allowing unanticipated behaviors to emerge. Agent-based simulation makes it easier to validate and calibrate the model through expert judgment because the agent-based description the model is using is often the most appropriate way of describing what is actually happening in the real world, and operators can easily "connect" to the model. In military science, models have to be intuitive and easily understood by the practitioners of combat; otherwise no one will use the model. By identifying the agents in a system and modeling their activities, the model can express very complicated dynamics in simple, easy-to-understand terms. In summary, ABM is a more natural, understandable, and convincing method than traditional techniques. In future concept development, for which there is no historical data, ABM provides an immensely valuable improvement.

2 AGENT-BASED MODELING AND CONCEPT DEVELOPMENT

The success of future military operations depends, in part, on a Commander's ability to quickly analyze the current complex and dynamic situation and then make decisions which best leverage advantage in, say, speed and flexibility in deploying available assets. Future military operations will likely involve hundreds of assets, both manned and

unmanned, each with potentially different capabilities and complicated command and control systems. The analysis and comprehensive understanding of this kind of complex system is extremely difficult and in most cases impossible for humans to grasp without the assistance of advanced tools such as agent-based simulations. ABM technology gives concept developers a view to the future by enabling them to simulate and manipulate in near real-time, the assets and operational conditions for which a commander must make tactical decisions. From a scientific point of view Red and Blue forces make up a dynamic, non-linear, complex adaptive system in which the overall system behavior emerges from the aggregate interactions among individual agents (assets). An ABM is a valid way to model this level of complexity. The focus is to identify main components and to discover their local interactions and behaviors. It is from the local interactions of individual components and their behaviors with their environment that global system behaviors emerge, and subsequently, the developer's window to the future.

This paper discusses techniques for using agent-based modeling for military future concept development. There are at least five important steps in concept development for which ABM provides extraordinary promise:

- Concept Exploration
- Concept Validation
- Deliberate Analyses
- War Game Adjudication and Player Support
- Field Experimentation and Operator Support.

The goal is to continuously and cumulatively generate a formal knowledge base of effective tactics, technologies, and force structures for future military operations.

2.1 Concept Exploration

In the concept exploration phase, developers look at notional concept under a broad range of operational factors in a competitive context. Care is taken to prevent developers from over-constraining the inputs to the model – concept exploration welcomes counterintuitive results, unexpected behaviors or extreme cases. Without such an unbiased search, innovation can be gravely affected. The aim of concept exploration is to inform formal definition of a proposed concept by gaining a deeper understanding of the notional concept, possible advantageous dynamics, and important factors in the competition and environment.

2.2 Concept Validation

As exploration of a concept continues, the results of ABM will create a body of empirical evidence that will bring the proposed concept into tighter focus – deeper patterns may emerge, for example, or a more technical definition of the mechanisms of advantage may result. Using the ABM-derived data, developers can begin to explore the extremes and limits of the proposed concepts and identify the contexts in which the concept is valid and those in which is not. Here, ABM is a perfect tool to implement the Scientific Method – developers can quickly and efficiently produce an extremely large set of scenario runs to test for instances in which the "Null Hypothesis" (the case for which the concept is invalid) is true.

2.3 Deliberate Analyses

Once concept validation is satisfactorily complete, developers can use ABM to take a more finely tuned look at the more narrow set of variables proscribed by the valid concept. Within a narrower set of variables, however, there still exists a very large trade space in many dimensions. Again, ABM techniques are excellent tools for determining the appropriate mix of attributes for the forces and tactics contained in the concept.

2.4 War Game Adjudication/Player Support

Quite often, concept developers test a new concept in the abstract operating environment of a war game. In war games, ABMs can be useful in at least two ways: to adjudicate player decisions and to support player decisions. ABMs are useful for adjudication because they are both easy to set up and run (thus offering timely adjudication, a traditionally difficult and expensive task) and because very many runs can be accomplished in a short time (mitigating the occasional "outlier" results that can stem from traditional techniques). ABMs are useful for player support, because they can be used by the Commander's staff to explore a great range of operational options, rather than the usual three courses of action generated by lock-step planning processes.

2.5 Field Experimentation/Operator Support

In many ways, Field Experimentation is analogous to war gaming, if only in that the operating environment is artificial and abstract. ABMs are useful for Field Experimentation as well, serving as adjudication or stimulation tools and planning tools for a Commander's Planning Staff.

3 CASE STUDY: NAVAL OPERATIONS

In recent years, naval concept developers have been stymied in their research and analysis into two areas directly affecting the future force structure of the Navy. These two research areas, distinct yet closely related, are (1) the next generation or surface craft and (2) the use of networked, uninhabited vehicles. To date, research on these topics has been limited by the analytical tools available to the develop-

ers. This case study will discuss the two research areas in more detail and provide a summary of how new tools might help concept developers productively conceive of and develop advanced operational capabilities, innovative tactics, and new force employment options for future naval forces.

One of the most controversial analytical questions faced by navy concept developers is the appropriate constitution of the surface force of the future. In one camp are traditional naval operations research analysts, naval architects and surface warfare officers who argue that a new class of large, multi-mission surface craft should evolve from the existing capabilities and industrial base. The flagships of this camp are the DD(X) destroyer and the CG(X) cruiser. Alternative platforms have been advocated by another camp, who suggest that a new family of revolutionary small, fast combatant craft should be built to fight in littoral seas. This group has nominated the Littoral Combat Ship (LCS) as an experimental platform to explore the utility of small ships.

Exacerbating the controversy is the fact that the traditional mathematical constructs used by naval analysts for decades support large ship solutions. Small ship advocates suspect that the analytical preference for large ships is due to a choice of models and not due to an inherent superiority of large ships over small ships. In particular, the small ship camp maintains that large models do not well capture the value of such operational concepts as dispersed combat power, swarm tactics, or decentralized command and control. In existing models, they contend, these concepts must be scripted, preventing the opportunity for a rigorous assessment of the potential for emergent behaviors and adaptive tactics. There is credence to these criticisms of the existing modeling suite.

The development of an agent-based simulation for the express purpose of exploring the next generation of surface combatants would help resolve the conflict between the two camps by creating a tool specifically designed for the task at hand rather than relying on traditional models that may not capture revolutionary capabilities. Including this tool in an analysts' suite would help explore such issues as:

- The role of speed in combat in the littoral
- The limits to which payloads can be reduced without compromising collective success
- How search strategies might change when more yet smaller craft are added to a traditional force
- The extent to which survival of the entire force is impacted when smaller ships are employed
- How dispersal and distribution of combat power affect overall force effectiveness
- Conditions in which a mix of surface craft might be superior to all-large or all-small surface forces
- New tactics that might make small ships superior to large ships
- Command and control structures that might favor a distributed force over a concentrated force.

Moreover, small ship advocates suggest that uninhabited surface, air, and subsurface vehicles will accomplish some of the searching as well as the delivery of combat power. For some, the mature development of these vehicles is a prerequisite to a small ship investment strategy. Therefore, as the future of the surface fleet is contemplated, questions about the employment of uninhabited vehicles are closely tied to other questions and issues about fleet mix, tactics and command.

The same problems encountered with attempting to model small ships with existing models even more dramatically impact attempts to model large numbers of small, autonomous vehicles. Designing a tool for the express purpose of examining uninhabited vehicles would fill nagging gap in naval modeling capabilities and help address such issues as:

- The appropriate mix of manned and unmanned vehicles for a future force
- The conditions under which unmanned vehicles might be desired over manned vehicles
- The trade-offs between large numbers of small unmanned vehicles and small numbers of large manned vehicles
- Appropriate rule sets for search, detection and tracking
- The extent to which platforms collaborate without direct central control and still accomplish tasks
- The extent to which central control is required to accomplish a task
- The trade-offs between endurance, numbers, range and speed for a group of uninhabited vehicles to accomplish certain tasks
- The co-evolution of tactics and countermeasures between autonomous vehicles and an enemy force
- Potential for developing new tactics and operational concepts.

The use of ABM modeling throughout the concept development process may have a direct impact on the Navy's ability to resolve these critical force structure issues, inform the acquisition of future surface force platforms, and determine the future use of uninhabited vehicles in a naval force.

3.1 Concept Exploration

The use of ABM in naval concept development might start with an effort to examine the mix of basic elements that might make up a future naval surface force. For example, developers could initiate a two- to three-month explorative effort to look at the role of speed, numbers, armoring, firepower, surveillance, cohesion, distribution, rudimentary

networking, the environment, missions or different command structures. The aim of this effort would be to inform the formal definition of a proposed naval surface force operational concept.

3.2 Concept Development

Following this effort, concept developers might spend one to two months validating the proposed concept. During this phase of development, analysts would derive potential hypotheses from the earlier exploration data set and then construct small experiments or cases to test these hypotheses. Figure 1 shows the results from an actual concept validation effort. Early in the development of small ship concepts, many thought that speed was a universal good for small ships, and so the requirement for high speed was prominent in the operational concept. After less than a week of effort, analysts found that speed was not universal, but conditional, because they found cases in which increased speed decreased survivability, directly contradicting the proposed concept. In Figure 1, note that the "AvgBSurv" (average Blue agents surviving) decreases as the ratio of Blue speed to Red Speed increases from 2:1 to 4:1 (note: this is captioned as opposite in the figure). As a result, the concept was modified with conditional, mitigating language. Importantly, backing off from an extreme view of speed strengthened the concept rather than weakening it.

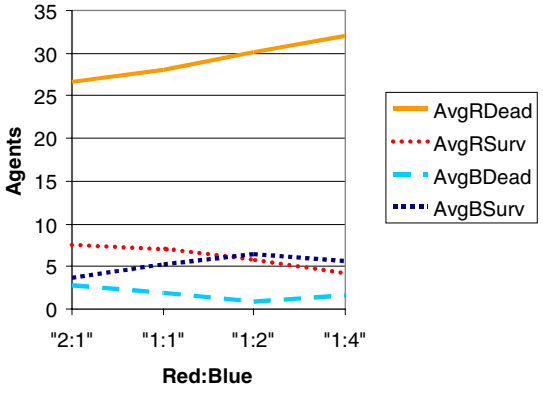

Figure 1: Validating Speed with an ABM

3.3 Deliberate Analyses

Once the validation phase is complete, developers might spend two to three months conducting a detailed analysis of the parameters and dimensions of the concept. The goal would be to discover critical combinations of factors (mission, vehicle speed, surface search range, undersea search range, weapons capabilities, inventories, etc.) that tend to produce certain output phenomena (desired or otherwise) in the agent populations. The results of this effort would include development of experimental tactics, refined technical requirements and a more focused operational concept. These results will also be useful as inputs to the war gaming and experimentation phases.

3.4 War Game Adjudication/Player Support

Naval concept developers could use ABM to perform first order, quick-turn-around combat adjudication to support umpire efforts during war gaming. Importantly, analysts should also have expertise in the traditional modeling suites, so that war game adjudication results from the agent-based simulation can be assessed consistently and commensurate with traditional adjudication results. In addition, concept developers with experience in operational and tactical level of war joint planning issues, as well as expertise in the operational and issues surrounding the future surface force should be placed with both the Red and Blue Commander's staff to provide the ability to game out first-order approximations of likely force mixes employment options, potential strategies for search and detection, and possible attrition or exchange rates.

3.5 Field Experimentation

In much the same way, naval concept developers could use ABM to perform first order, quick-turn-around combat adjudication and rudimentary stimulation to support experimentation. Likewise, analysts should have expertise in experimental design and execution, so that stimulation from the agent-based simulation can incorporated with traditional methods. Also, concept developers with experience in operational and tactical level of war joint planning issues, as well as expertise in the operational and issues surrounding the future surface force should be placed with both the Red and Blue Commander's operational staff to provide the ability to game out first-order approximations of likely force mixes employment options, potential strategies for search and detection and possible attrition or exchange rates. In this way, ABMs could also serve as prototype tactical decision aids (TDAs) for use in real-world operations in planning and executing operations in the littorals.

4 CONCLUSION

Recognizing an analytical gap between existing problems and useful solutions, this paper has presented techniques for and a potential case study of the use of agent-based models for military concept development. Their use for this purpose has been extremely limited to date and while the paper suggests promising productive efforts, since concept development is itself a complex and adaptive enterprise, more techniques and types of efforts are likely to emerge from continued use. Whether or not any ABM techniques will be employed remains an open question.

ACKNOWLEDGMENTS

The author wishes to acknowledge the contributions of the scientists and analysts of BiosGroup, Inc., for comments on and guidance in the use of agent-based models for military concept development.

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