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SIMULATION-BASED ACQUISITION: AN IMPETUS FOR CHANGE

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ABSTRACT

The military has recently introduced simulation-based acquisition where simulation technologies would be applied throughout all phases of system design, development, production and deployment. Originally, a four-phase approach was defined to reflect the sequential steps occurring from the initial conceptualization of the system to its eventual deployment. In this paper, the acquisition process is redefined as a collection of concurrent functions that may be iteratively implemented throughout the acquisition process. Potential applications for simulation in this enhanced acquisition process are discussed. In addition, the need for further simulation development is conveyed.

1 INTRODUCTION

The goal in writing this paper is to provide an overview of evolving efforts to apply simulation as a comprehensive support tool in the acquisition of military systems. This concept was formally introduced in Fallin (1997). In recent years, other articles on this topic have occurred, and perhaps the most comprehensive description is contained Johnson, McKeon and Szanto (1998).

In preparing this paper, I have employed a very general definition of simulation that includes the use of a model to project the performance of a system. Because the system's acquisition process is complicated, we can expect that the potential exists for the use of simulation models within several functions. However, given the potential for multiple applications, it is also expected that several different forms of simulation will be employed. The goal of this paper is to discuss the following:

- The functions that comprise the proposed simulation acquisition process,
- The types of simulations that might be employed in each of these execution functions,
- The ways in which these acquisition functions might interact with each other,
- The simulation tools that can support this interaction, and
- New developments in simulation that might evolve as the acquisition problems are addressed.

We will first discuss the basic concepts as originally described in Fallin (1997). Here, four basic phases for the acquisition process were defined:

- Phase 0—Concept Exploration. A new weapon system is conceptualized in order to determine what new capabilities the proposed weapon system might provide in battle applications. This conceptualiza-tion should also consider how personnel will be trained in the new tactics that will be needed in order to deploy the proposed system in a battle setting.
- Phase I—Program Definition & Risk Reduction. The system requirements are refined in order to provide a detailed set of specifications that can be implemented through engineering design and manufacturing. This effort should specify the actual capabilities the proposed system will provide, the personnel requirements that will be needed to operate the system, what additional resources will be needed to support its employment, and basic cost projections.
- Phase II—Engineering, Manufacturing and Deployment. The detailed specifications for translating the proposed system design into an operational weapons system are realized. A detailed engineering design is executed and then implemented by the manufacturing of the system. In addition, detailed training programs must be developed to train the personnel that will operate the system.
- Phase III—Production Fielding, Deployment and Operational Support. The systems are deployed. Detailed training occurs. Tactics are refined for employing the system in real-battle missions. When the new system has been placed into operation, the strategies for maintaining the systems in order to insure their operational readiness are also refined.

Unfortunately, the above time-phased evolution for the simulation-based acquisition (SBA) process does not reflect the iterative cycles that must occur as a weapon system is conceptualized, designed, manufactured and deployed. Even in the design of an entirely new weapon system, iterative cycles will occur as concepts are proposed, refined, and subsequently pursued for implementation.

Moreover, weapon system acquisitions often involve upgrades to existing systems, not entirely new systems. In fact, several different versions for a given weapon system can be deployed concurrently. Consider the M1 tank or the F15 fighter, which were designed in the Seventies and deployed in the Eighties. During their lifetime, each weapon system has undergone many upgrades. Some of these upgrades were initiated in order to incorporate new technologies. Others were initiated to re-engineer existing subsystems. This latter case is particularly appropriate when one considers electronic subsystems. The technologies and components that were employed to assemble circuit boards in the Seventies and Eighties have been replaced by today's new technologies. Many of the components employed in the original circuits no longer exist. The Department of Defense's (DoD's) former Rapid Acquisition of Manufactured Parts program attempted to address this need by establishing the state-of-the-art agile manufacturing environment for designing and manufacturing replacement parts.

Two important observations can be made. First, other causes can trigger the initiation of Phase 0 besides the obvious conceptualization of new weapon system. Second, a given weapon system can exist concurrently within several phases. The acquisition of a weapon system is an ongoing activity, which leads to a constant reconfiguring and updating of the implemented system. The goal of this paper is to develop a representation for the acquisition process that reflects the iterative nature of the acquisition process.

2 SIMULATION-BASED ACQUISITION AS AN ITERATIVE PROCESS

Figure 1 provides an alternative concept of operation for the system acquisition process. The interconnections among the included processes is obvious. Let us begin with the System Development Management Function (located at the top center of the figure). As illustrated, this function accepts inputs from several other functions. Let us postpone for the moment the discussion of these inputs and move directly to this function's output which provides the general specifications for the desired system.

The generation of the system specifications initiates the overall design process. In Figure 1, these specifications are input into the Computer-Aided Design function. We will assume that the output of this function is a design, which has been captured in a standardized electronic format so that it can be transferred to other functions. The computer-aided design software that generates the design can itself be viewed as a simulation. Indeed, the efficacy of such software is dependent upon its ability to capture (simulate) the design process employed by its user.

The next step is to assess the capability of the initial design to satisfy the proposed design objectives. Two alternative approaches might be adopted to make this assessment. The first approach is to construct one or more physical prototypes, which can then be tested. Although this approach might provide the most realistic assessment, prototypes are expensive. The second approach assesses the design using analytical models and physical simulations. In a complex system, we can expect that numerous simulations of each subsystem will be performed. For example, specialized simulators will be employed to test the design of a proposed electronic board. Finite element packages may be employed to simulate the strain response of a given mechanical component when it is subjected to a given load. More sophisticated tools might simulate the behavior of the same component under repeated loading cycles in order to assess its reliability.

In addition to characterizing the behavior of individual subsystems, other comprehensive simulation studies must address the interoperability among the subsystems in order to assess the overall system's performance. For example, the Army has invested considerable funds toward the development of tank simulators. Using such simulators, one can project the performance of the system in real-battle situations including the tank's dynamics as it moves over different types of terrain as well as the accuracy of its included weapon systems. The projected performance characteristics must then be compared to the design constraints in order to improve the functionality of the proposed design objectives.

It is likely that physical prototypes will always be needed, particularly when technological frontiers are approached. The goal, however, is to minimize the number of prototypes, particularly during the early conceptualization phase of the project. Simulation provides an alternative, but it is unlikely to entirely replace the need for prototypes. Simulations also permit one to efficiently use prototypes. For example, experimental design procedures can employ simulation models to determine which design factors are most critical to the overall performance. This criticality assessment can subsequently lead to more focused experiments with the prototype. Moreover, the results of experiments with the prototype can provide additional data to validate and improve the simulation models. A symbiotic relationship evolves between the experimentation with simulation models and prototypes.

We further expect that the design cycle for new subsystems within an existing weapons system will continue after the system is deployed. In this case, experimentation with the deployed system provides another means of prototypical experimentation. However, one must design

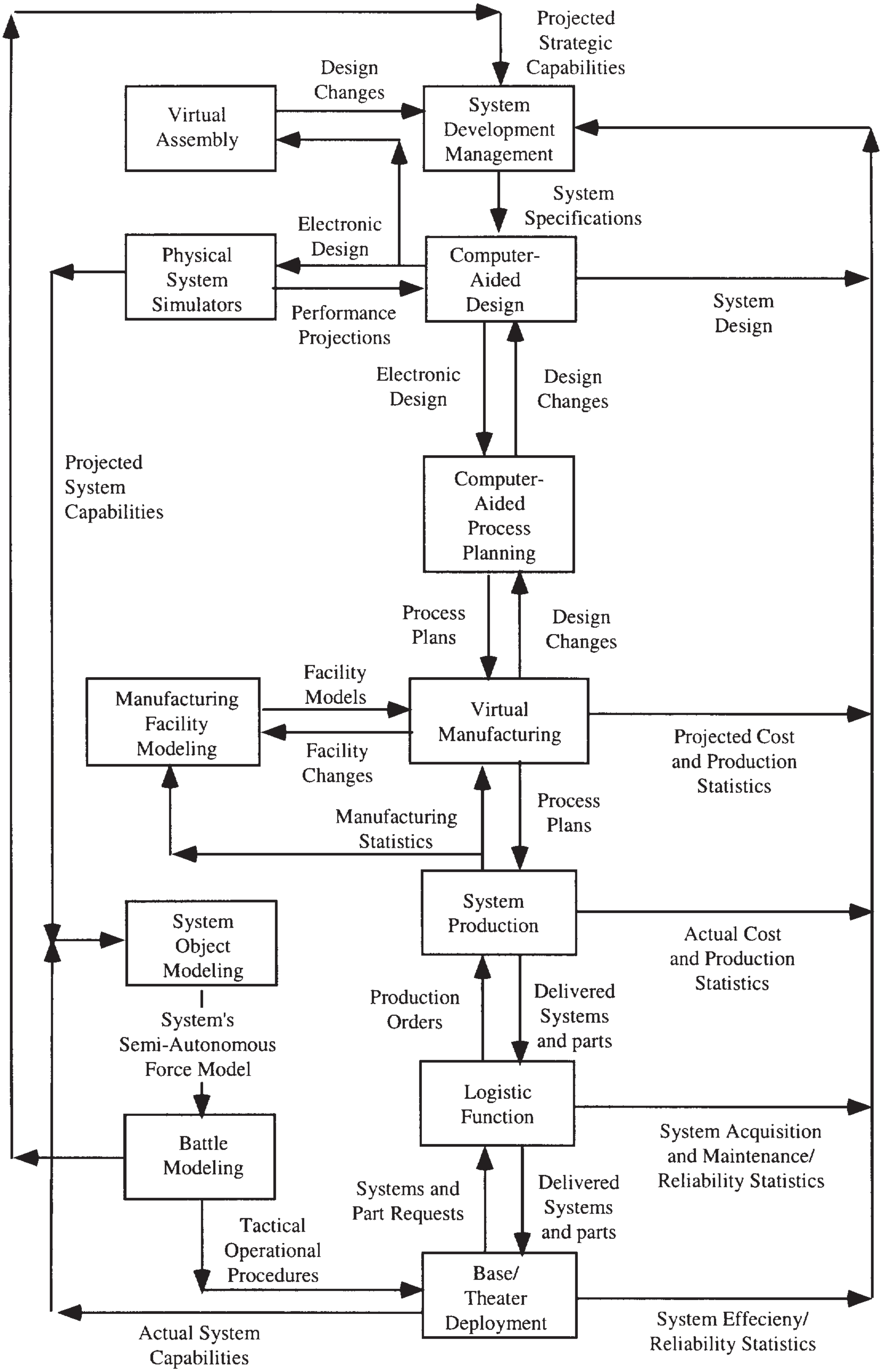

Figure 1: Schematic for the Overall System Acquisition Function

prototypes for the given subsystem to be incorporated within an existing system for testing purposes, and this can be expensive and time consuming.

Other forms of physical simulators now exist, which have also revolutionized the design process. A major concern here is to assemble the subsystems into an overall system. The designer must verify that the physical location and movement of one part will not interfere with another and that all tolerances for the physical mating of parts are appropriate. In the past, physical prototypes were essential to this assessment. Today's computer-aided design tools can virtually assemble the subsystems into a simulated prototype. The design of the Boeing 777 represents one example where virtual assembly was applied. The cost/time savings here are significant.

As illustrated in Figure 1, an iterative cycle exists between the formulation of the design specifications for the system, the generation of a design, and the assessment of its performance capabilities. The overall goal for these iterative design cycles is to insure that a physical system can be realized using available engineering capabilities. Hence, the physical laws of science and engineering impact the design process, and the constraints upon the designed system must be understood.

The strategic/tactical advantages of a proposed design must also be assessed. Tactical models for the proposed system can then be employed within battle simulations in order to assess the strategic benefits that the new system will provide. By analyzing various battle scenarios, one can then assess strategic benefits resulting from a given set of design constraints as well as the logistic consequences derived from employing the proposed system in a simulated battle scenario. Using such strategic analyses, additional iterative cycles evolve in the design of the proposed system.

Another major consideration in designing any engineered system is its projected life-cycle cost. The life-cycle cost includes several component costs: the initial manufacturing/procurement costs, the maintenance/operation costs and the training costs associated with deployment.

The new approaches to concurrent engineering design attempt to assess the manufacturing costs associated with a given design before it is committed to full-scale production. Simulation is once again an essential tool in performing this assessment. Assume that a digital representation exists for each component within the proposed system. This electronic design can then be passed to a computer-aided process planning tool which will develop the detailed processing instructions that are required to manufacture components. In order to generate these process plans, one must first specify the types of equipment that will be employed in manufacturing the component. The computer-aided process planning tools then simulate the design efforts of the process planners as they determine how to manufacture the part using the specified equipment.

When the processing plans are generated, they can be forwarded to the virtual manufacturing function. Virtual manufacturing can employ several modes of simulation analysis. Today, virtual processing software can emulate the execution of a specified set of processing instructions for a given piece of equipment. Such virtual processing capability is particularly useful in order to verify the correctness of a given set of processing instructions.

The major concern of the virtual manufacturing function, however, is to assess the manufacturability of the overall system. That is, the concern is one of assessing the cost and production capabilities for manufacturing the proposed system within an existing or proposed manufacturing facility. To this end, discrete-event simulation tools model the facilities that will manufacture the product. Unfortunately, the existing simulation tools have limited capability for providing such assessments. Some of the current limitations include:

- Current simulation tools are incapable of directly employing the information contained within the processing plan. Instead, they force the modeler to aggregate the process plan into two pieces of data: the time to perform the processing step and the reliability of executing the step. Thus, current simulation tools are incapable of assessing the impact that the more detailed production constraints will have upon the proposed manufacturing.
- Current tools are capable of modeling a single manufacturing cell or line only. Models of individual cells cannot be integrated in order to develop models for an entire manufacturing facility. Furthermore, current simulation tools cannot assess the consequences that an existing control architecture that coordinates the production among the lines has upon the system. The manufacture of a complex system will likely require coordinated production among several manufacturing lines or facilities. In addition, these facilities will likely be geographically distributed throughout the country or the world. The goal is to link all of these remote facilities into a single virtual enterprise when full-scale production of the system is initiated. The current tools typically only model a single subsystem with limited detail. It will be difficult to capture the "system of systems" nature that characterizes most complex systems using current tools.

In order to support virtual manufacturing, new simulation tools must provide the following capabilities:

- They must address the detailed process plans. In addition, they must consider the detailed resource requirements needed to execute each processing step.

This capability is essential when one attempts to implement activity-based accounting procedures for estimating the true costs of manufacturing a given component or subassembly.

- They must effectively model distributed manufacturing systems and thus capture the system-of-system nature that characterizes the virtual enterprise for manufacturing the designed system. In particular, they must consider the control architectures that are needed in order to coordinate production across several manufacturing cells and facilities. In fact, the simulation model itself should provide the control architecture that is needed to manage the integrated manufacturing system.
- They must employ distributed simulation and maximize the use of the World-Wide Web.
- The web should provide a means to model sharing as well as perform collaborative simulation analyses associated with the functional interactions as shown in Figure 1.
- Finally, they must support on-line simulation analyses for the development of advanced intelligent control capabilities that are needed for the distributed on-line management of these systems.

The output of the virtual manufacturing function is a set of detailed cost estimates and production capabilities for manufacturing the proposed systems, which are returned to the system management function as feedback information. Thus, the development management function can then initiate another iterative design cycle to enhance its manufacturability.

After the design is finalized, production can be initiated. The new simulation models should immediately specify the distributed control structure for managing the virtual enterprise. The same models should also support on-line simulations that allow a production manager to constantly project the future performance of a given subsystem given its current system state as it operates under alternative control strategies. Advanced intelligent control capabilities can be then defined to effect these projections using on-line planning and control. Once system production is initiated, actual cost and production statistics can be collected. This information is again returned to the system development management function, thus providing another iterative design cycle.

The likely source for the production orders will be a logistic function. Orders for the primary systems will be generated as well as orders for replacement parts. These production orders will satisfy the needs of the military bases and theaters where the systems are (or will be) deployed. Based upon the demand for spare parts and manufacturing capability, the logistic function can provide system acquisition and reliability statistics to the system development management function. These statistics also permit the logistic functions to perform other simulation analysis in order to assess the inventory levels and distribution of spare parts that are needed to support both peacetime and wartime efforts. In a sense, the logistic function can employ simulation to assist in forecasting future demand and to assess its ability to meet that demand given existing manufacturing capabilities.

Based upon training exercises as well as actual wartime usage of the system, the system's military customers can provide statistics relating to the efficiency and reliability of the system. These statistics are returned to the system development management function to initiate further design improvements. The effectiveness and reliability of the system is dependent upon the manner in which the system is employed. A critical concern here is the development of standardized operational procedures and tactics for employing the system. This procedural development provides another iterative activity which is dependent upon both the design and prior experience with the weapons system.

The development of standardized operation procedures and tactics for employing the system will employ at least two types of simulation. The military has already developed sophisticated physical simulators for many weapon systems (e.g. tanks, aircraft and so forth). These physical simulators have at least two major functions. First, they are useful in training students before they attempt to operate the real system. The benefits here are obvious. The second use of a physical simulator is to assess the efficacy of proposed operational procedures before they are employed in a training or military exercise. This approach is particularly useful when one is attempting to assess the maximum performance envelope of the system. A similar use has already been adopted for the public sector also. For example, a simulation for a given aircraft will be employed after a crash in order to determine if there was a way that the crash could have been prevented. When a new operational response is learned, it can be incorporated into the overall training regiment. We can assume that a similar situation exists in the military.

There is also the issue of how the system should be employed in a given battle scenario. The desire is to maximize the benefits of deploying the weapon system while minimizing casualties and losses. One must also assess the logistic requirements that will ensue from implementing a given tactic and the overall reliability of the system when it is employed in a proposed operation. Again, simulation plays a key role here. Based upon real-world experience, the simulation force model for the given system can be continuously updated and improved. (Here one can assume that the system will be employed in training scenarios before it is employed in a combat setting. These training scenarios will provide the data needed to update the weapon's models.) This model can then be employed within a battle simulation model where different tactics for the system's use are tested and its performance assessed. Whenever a new tactic appears to be promising, it can be further tested in training exercises. The outcome of these exercises can then be employed to improve the simulation models. It is again obvious that the construction and testing of the system models is an iterative effort.

3 THE FUTURE

The most obvious benefits of the SBA initiative will be to reduce the design cycle and to increase the quality of future the future weapon systems developed by the DoD. These same advantages could also be realized in the upgrading of the current weapon systems. However, given the breadth of the proposed SBA initiative, its impact upon the future of simulation could also be formidable. The DoD is probably the largest end-user of simulation technologies. They are certainly one of the major investors in the simulation research that will drive the development of future simulation technologies. The SBA initiative provides an unique opportunity whereby the technologies of system design and acquisition can be advanced with the basic simulation technologies.

The DoD has many ways to approach this problem. The first choice is to determine the level of complexity to be addressed. To consider the SBA problem as a serial sequence of four steps is the simplest approach. It is also the easiest to implement with available simulation technologies. Unfortunately, the benefits accrued from the serialization of the SBA process will have limited impact in both the simulation and acquisition sectors. The greater concern resides with the acquisition process because it is an iterative, not sequential, process. Hence, any developments derived from assuming that the acquisition process is sequential are suspect. What benefits can a derived solution provide when the inherent iterative nature of the acquisition process forces one to revisit an earlier step? What portion, if any, of the prior analysis is valid?

To acknowledge the iterative/non-sequential nature of the acquisition process is to significantly complicate the issue. However, to address this complexity is to provide better tools in support of the acquisition process and to advance the simulation technologies employed. Hence, the DoD gets better systems, and as a by-product, new simulation technologies that it can exploit.

Why will new technologies be needed? If one adopts the sequential approach to SBA as originally defined, then perhaps there is little need for advanced technologies because the required simulation analyses can also be executed in a sequential fashion. One must, however, be cognizant of the limitations that the current simulation tools provide in modeling a given system. When a sequential analysis is adopted, the translation of output data from one simulation into input data for a subsequential analysis can often be performed as a separate step. On the other hand, if one considers the concurrent iterative cycles suggested in Figure 1, then it becomes almost impossible to execute sequentially the simulations associated with the analysis. Furthermore, the output of one simulation can provide input data for several other simulations. Moreover, the form of the input data required by the other simulations may differ. One simulation may require different data, while two other simulations could share the same data at different levels of resolution.

Clearly, the potential for distributed simulation exists and one might attempt to consider the new standards such as the High Level Architecture (HLA). However, HLA would tend to hide most of the interrelationships associated with Figure 1. HLA would presuppose that any function could interact with any other. Furthermore, the specialized needs of translating one simulation output into the specialized forms needed by another simulation could be tricky. In general, one simulation analysis would need to broadcast its output throughout the confederation in every possible format that might be needed. HLA might address this need, but it may not be the most efficient means for integrating the distributed simulations.

Another technological need is the provision of simulation tools that are capable of handling the output information generated by other simulation analyses. As in Figure 1, the output of the computer-aided design function (the electronic part description file) serves as input to the computer-aided process planning function. This capability does exists. Furthermore, the output of the computer-aided process planning function, the process plans, can be virtually emulated by several virtual processing tools. However, these same process plans must also be considered by the simulation models of the manufacturing facilities where the processing will occur. Most manufacturing simulation tools cannot consider process plans in any form.

Facility modeling and design must provide the control architecture that will manage the production. Most manufacturing tools cannot assess the consequences that a given manufacturing hierarchy will have upon the performance of the manufacturing facility where it is to be employed. Davis (1998) discusses many other limitations of current simulation tools, most of which will impact the SBA process.

The DoD will determine the levels of comprehension and accuracy for addressing the overall SBA process. Certainly one option is simply to tolerate the current technologies and the inaccuracies that are likely to occur. In order to account for potential cost inaccuracies, it can either overestimate the costs to cover any potential or live with the potential that cost overruns are possible. In the first case, the inflated cost will make the project harder to sell. In the second case, there is also political capital that must be spent to explain cost overruns.

Dealing with inaccurate performance estimates is an entirely different issue. The DoD must be sure that the desired tactical benefits are achieved. Furthermore, it should be able to calculate the trade-offs of achieving the desired benefits against the increased costs and maintenance requirements. Such decisions ultimately impact our military readiness and capabilities.

For example, one should know from the outset that it may require several weeks to deploy a sophisticated system and that the system should not be considered as an available option for responding to a fast evolving crisis. A weapon system may also have particular problems while operating in a given environment. Finally, the logistic needs will determine the difficulty of maintaining the system in the battlefield.

Corporate experience has demonstrated repeatedly that the investment costs associated with improved design processes are profitable. Given the military's need to replace aging systems, some of which are over two decades old, and given tight defense budgets, it is clear that the military must make judicious choices about the systems to be pursued. The first of these investments should implement the SBA procedures as discussed here. However, before these investments are made, the military should take time to really understand the overall acquisition problem. Each function should be studied in detail to define its role in the acquisition process and how the given function will interact with the other functions. Given this definition, the next mission is to determine the simulation capabilities that will be needed to address each function as well as the information that will be needed to support the analysis.

When the simulation requirements are defined for supporting each function, then one can assess the current technological capabilities to satisfy those needs. Given these limitations, the military can either tailor its analysis within these constraints or seek new simulation technologies.

In Davis and Moeller (1999), I raise similar concerns about the manner in which the High-Level Architecture was defined. In developing HLA, the military's primary goal was to integrate the existing simulation models. The definition of the overall goals for the integrated/comprehensive simulations and the simulation capabilities that were needed to achieve these goals appears to have been a secondary concern. The military has subsequently demonstrated the influence that it has upon the simulation community through its it efforts to have HLA adopted as the standard for distributed simulation by both the Object Modeling Group and IEEE.

The way in which the military approaches the SBA process will severely impact the simulation community. The research monies invested in melding simulation technologies to the acquisition process will govern the major technological advancements in simulation. Because the military itself is a major member of the simulation community, its future capabilities will be dependent upon judicious choices made today.

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