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THE ROLE OF DISTRIBUTED SIMULATION IN DEFENSE ACQUISITION

Marvin H. Hammond, Jr., *Task Leader*

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This paper examines the role that distributed simulation could play in incorporating the latest design, engineering, manufacturing and support technologies, and management practices in DoD's acquisition system. These improved technologies and practices have allowed some of the most progressive commercial firms to reduce development time and costs by up to 50 percent. Three advances have made this possible: (a) the diffusion of new management approaches such as integrated product and process development (IPPD) and Total Quality Management (TQM); (b) rapid improvements in design and manufacturing technologies; and (c) the increased power of distributed communications networks linking dispersed elements of design teams. We discuss how commercial firms and defense programs have used distributed simulation technologies in conjunction with these three advances to provide a basis for coupling simulation investments with acquisition process improvements. Specific investment areas are identified which would aid the DoD and its suppliers to adopt these advances.

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PREFACE

This document was prepared by the Institute for Defense Analyses (IDA) under the task order, Application of Distributed Manned Simulation to the DoD Acquisition Process, for the Advanced Research Projects Agency (ARPA). It fulfills the objectives of the task, to identify the nature of the support simulation can provide to the various phases of the acquisition process and to characterize the general simulation environments and associated methods for applying them.

The following IDA research staff members were reviewers of this document: Mr. Thomas P. Christie, Dr. Harlow Freitag, Dr. Richard J. Ivanetich, Mr. Christopher Jehn, and Dr. Karen J. Richter.

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EXECUTIVE SUMMARY

The Department of Defense (DoD) acquisition process involves many functional communities, each with its own responsibilities for and perspectives on proposed new programs. These functional communities include:

- Requirements and Concept Development
- Engineering Design and Manufacturing
- Test and Evaluation
- Logistics and Support
- Force Planning and Budgeting
- Program Management

Each community performs its own trade-off analyses on proposed new system designs, and interacts in successive iterations of the design and needed supportive processes as the design converges toward that of a final production item.

This design-convergence process has parallels in the commercial world, where product development in large corporations also involves the interaction of powerful functional communities. Some of the most progressive companies have substantially reduced the time and cost—by up to 50 percent—of developing new products by incorporating the latest in design, engineering, manufacturing and support technologies, and management practices. Such companies, notably in the automotive, aeronautical, and electronics sectors, are capitalizing on advances in three areas:

- New management practices, including integrated product and process development (IPPD) and total quality management (TQM);
- Improved design and manufacturing technologies, including computer-aided design (CAD) tools and flexible manufacturing systems; and
- The increased power of distributed communications networks linking dispersed elements of design teams.

Simulation has aided many companies in implementing these advances. It entails the ability to represent the properties and performance of systems. Simulation offers four capabilities that can support timely and effective communication, and thus help to integrate functional communities into a unified program design team. First, simulation can be used to provide *visualization* of the product, which enhances communication both within and among functional communities. Second, it permits *performance modeling*, augmenting traditional analytical tools in creating and assessing design alternatives. Third, when coupled with distributed communications capabilities, simulation tools can provide design team members access to a *common information base* on the product and its performance. Finally, *user interaction* allows rapid exchange of information, ideas, and concerns across both geographic and functional boundaries.

Defense acquisition programs could benefit significantly if these kinds of simulation capabilities could be applied in conjunction with new management practices to break down the traditional "stovepipe" organizational barriers that have inhibited coordination and communication in developmental programs. Such an acquisition environment would cut the time and cost of weapon development programs and significantly improve the management of program risk. The challenge is to implement both the technological advances in simulation needed to integrate defense development teams, and the management process changes needed to create a functionally integrated system acquisition process.

This study examined the current state of the art in applying simulation in defense acquisition programs to better understand the kinds of technical advances that will be needed. Our examples illustrate both the wide ranging application of simulation and the limitations in simulation capabilities. Simulation is currently being used *within* each of DoD's functional communities, and each community is expanding the modeling and simulation tools needed to perform its own development tasks. As yet, however, there has been little incentive for establishing common tools, data bases, validation methods, or data exchange standards *across* communities. This lack of commonality in tools and data has limited the role of simulation as a medium of communication across functional communities. Simulation will increasingly play this role, however, as capabilities advance. Three levels of capability will mark that evolution of simulation:

- *Functional distributed simulation*: Provides visualization and performance modeling within a functional community. Most existing simulations are of this type, and are widely used within both government and contractor portions of each functional community.

- *Cross-functional distributed simulation*: Provides common data and user interaction across functional boundaries. The limited capabilities that exist today lie in the use of combat simulators by the requirements, engineering, testing, and force planning communities. Data standardization activities, such as the Continuous Acquisition and Life-cycle Support (CALS) (previously known as the Computer-Aided Acquisition and Logistics Support) effort and the Product Data Exchange Standard (PDES), are attempting to remove barriers between the engineering and logistics communities.
- *Functionally integrated simulation*: Represents the long-range vision for the evolution of simulation, in which distributed simulation would eliminate the language barriers between functional communities. Each community could access a common representation of a design from a distributed enterprise network, visualize it in the manner most useful for that community's work, and perform needed analyses using the community's customary analytical tools.

The main recommendation of this study is that DoD establish a simulation investment strategy incorporating the long-term goal of creating a functionally integrated acquisition process. Creating the needed simulation capabilities will require investments in several basic simulation building blocks: general simulation hardware and software; defense-specific application tools; communication standards; behavioral methods and data; verification, validation, and accreditation (VV&A); and education and training. The DoD simulation community can most effectively emphasize initiatives and investments in those areas that will not be supported as a matter of course by commercial developers or the DoD functional communities. These needed initiatives and investments include:

- Designing a simulation architecture for a functionally integrated acquisition process;
- Preparing a user guide to current simulation tools, data, and applications to encourage the sharing of available capabilities;
- Developing cost and schedule simulation tools showing how advances in management practices and development technologies can be incorporated in structuring new programs;
- Developing distributed simulation security so classified, proprietary, and personnel sensitive data can be readily exchanged; and

- Investing in several specific simulation infrastructure areas which will directly benefit acquisition programs:
    - Build accessible data base libraries that capture prior experience and help prevent reoccurrence of mistakes;
    - Improve simulation development tools and methods, including those for VV&A, variable fidelity, and aggregation/deaggregation; and
    - Establish widely accepted standards to facilitate development and exchanges of models and simulations within and across functional communities.

In addition to these initiatives that relate directly to simulation, appropriate incentives need to be defined for organizations both within and supporting the DoD to help encourage them to adopt the key management principles which commercial industries have found necessary to attain a functionally integrated acquisition process. These principles are:

- Selecting strong program development leadership,
- Using functionally integrated development teams,
- Establishing clear communications and expectations,
- Conducting simultaneous development, and
- Implementing effective risk management.

This study provides the vision of a functionally integrated acquisition process based on the use of distributed simulation, and serves as a point of departure in creating a simulation investment strategy. This strategy should:

- Incorporate existing and ongoing advances and activities in the commercial world, each of the defense functional communities, and the suppliers to DoD.
- Assess the costs and benefits of the selected investment options.

Building this investment strategy will require active involvement of senior Office of the Secretary of Defense (OSD) leadership along with the participation of each of the DoD functional communities and DoD suppliers that support acquisition programs.

I. INTRODUCTION

Advances in management practices and technologies are revolutionizing the way U.S. products are developed and produced. Some firms can now cut up to 50 percent off the time required to develop and field new products while improving product quality and reducing costs. These advances have been made possible by developments in three areas:

- The diffusion of new management approaches for design and manufacturing, which includes total quality management (TQM), enterprise integration, and integrated product and process development (IPPD).
- Rapid improvements in design and manufacturing tools, such as computer-aided design (CAD), computer-aided manufacturing (CAM), and computer simulation.
- The growing ability to integrate these tools within distributed computer networks.

As more firms adopt these highly complementary developments, the resulting benefits will reduce development and production time, improve quality, and reduce costs in companies.

Many within the Department of Defense (DoD) and its suppliers are also seeking to adopt these advances by adapting such key commercial practices and technology advances to DoD management, organizational structure, and program developments. One important goal central to those advances is to create a functionally integrated system acquisition process which breaks down the traditional "stovepipe" or functional[1] barriers that inhibit coordination and communication in development programs. This paper focuses on the role

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[1] These include requirements and concept development, engineering design and manufacturing, test and evaluation, logistics and support, force and budget planning, and program management. The activities within these functional communities would include all events within a program's life cycle, i.e., "from lust *(the initial idea about the program)* to dust *(the results of the disposal)*." Examples of such activities (in addition to those implied by the function title) would be research, development, production, training, operations (users), support, education, planning (within each Service and Joint), costing, decision making (program managers, Defense Acquisition Board members and supporting staff), political efforts (supporters and detractors), and decommissioning and disposal.

distributed simulation could contribute within the DoD and its suppliers in capitalizing on these advances in management practices and technologies to improve the acquisition process.

Distributed simulation embodies two concepts. First, "simulation" supporting acquisition entails the ability to represent the properties and performance of physical systems during the development of a new or re-designed product, using a combination of live exercises or games, constructive models, or virtual reality [DSB Sim 1993]. Simulation offers two capabilities. The first is *visualization* which provides a powerful tool for communication both within and across functional communities. Visualization may be static, as in a mechanical component or assembly displayed within a CAD software package. Visualization could also be dynamic, as when the movement of mechanical components is displayed. Through the use of these simulation activities, the personnel within the many disciplines or functional communities will be able to be "immersed" into the operation, manufacture, repair, etc., of the system within the particular environment in which it would operate. The second capability is *performance modeling* which augments traditional analytical tools in creating a workable design. Such modeling could focus on simulating physical performance, such as the stress or heat dispersion of mechanical components. Modeling could also represent the operational characteristics of a component or weapon, such as reliability or combat effectiveness.

The concept of "distributed simulation" entails two additional capabilities. The third capability is a *common information base* that can be accessed from or at different locations, providing team members with the most recent data on current design parameters, environments, and scenarios. Finally, the fourth capability is *user interaction.* Users could range from designers and analysts marking up drawings from remote locations to test pilots participating in simulated air-to-air combat. These capabilities allow simulation to bridge both geographic and functional boundaries. Combining all four of these capabilities into a distributed simulation creates an effective technology for creating the integrated, functional teams needed to implement the latest management practices.

At present, simulations of various forms are used throughout the many acquisition-related DoD functional communities, each of which is developing the modeling and simulation tools needed to perform its own development or analysis tasks. There is some degree of information sharing among those simulation tools, but the unification of those capabilities in a broad-band information network remains a vision that will probably take decades to fully realize. In this paper we examine the role of simulation given current capabilities as well as how the contribution of distributed simulation will grow as increasingly sophisticated technologies come on line.

Three main topics are discussed in this paper. First, to provide a framework for examining the roles of modeling and simulation, we discuss examples of commercial applications of the various new management approaches (e.g., IPPD, concurrent engineering, enterprise integration, and TQM), and describe a functionally integrated system acquisition process based on the central concepts within those approaches. We describe how management practices assist in coordinating activities among functional communities and how this has resulted in faster convergence on designs using fewer total engineering hours. Through those descriptions and examples we provide benchmarks and principles related to a functionally integrated system acquisition process. Second, we describe the current uses of distributed simulation in DoD development programs. Three levels of simulation are considered in order to capture the current state of the art and to show how the contribution of simulation will grow as technology advances. Third, we examine the implications of our findings for the DoD's simulation investment strategy and discuss an agenda for applying distributed simulation in the acquisition process. A concluding section summarizes our findings and observations, and outlines a series of steps the DoD could take to create the simulation environment needed to support a functionally integrated system acquisition process.

II. BENCHMARKS AND PRINCIPLES FOR AN INTEGRATED DEVELOPMENT PROCESS

A major acquisition program will involve hundreds of government officials along with scores of firms, thousands of workers, and millions of work hours. Such programs will also include numerous teams from several functional communities for defining such aspects as program concepts, and developing product and process technologies, testing, logistics planning, budgeting, and oversight. The leadership and coordination of these teams in applying leading technologies present management challenges unmatched by virtually any other modern enterprise. For example, the current generation of aircraft in development incorporates such technologies as stealth, high performance engines, and advanced avionics and control systems. Those developments require the application of new materials and manufacturing processes, along with highly reliable software and control networks. The multiple technical challenges embodied in such programs present complex interactions among teams as development progresses.

A. LEARNING AND CONVERGENCE

A development project of such complexity involves learning about many unknowns within a systematic framework, with the purpose of converging on a design with well-understood properties. Key unknowns might include speed, weight, power, reliability, manufacturing process requirements, or any number of other characteristics. This learning and convergence process involves numerous cycles of analysis, design, fabrication, and experimentation both within each of the functional communities and across such communities.

Given the DoD's organizational structure and the legal environment in which the government procures weapon systems, we have identified six main functional communities involved in this learning and convergence process:

- Requirements and concept development: Military operators and technologists create the concepts for new weapon systems based on military mission needs and technological opportunities. Weapons requirements generally evolve from extensive concept studies that consider tradeoffs between operational utility, costs, support requirements, and affordable force size.

- Engineering design and manufacturing: Teams of designers and engineers create detailed designs for the weapon and its production. Such designs evolve from a series of design and trade-off analyses, which in turn evolve into a producible design implementing the weapon concept.
- Test and evaluation: Independent developmental and operational testers are required under law to validate the physical performance and operational utility of new weapon systems. Components and entire systems are submitted for such testing in laboratories and/or on test ranges throughout the development process.
- Logistics and support: As a program develops, the logistics and related communities plan for its fielding and support. Specifications are defined for training, maintenance, and spare parts purchases.
- Force planning and budgeting: Funding of programs flows through the DoD resource allocation process. Resource planners (within the Services, OSD, other Executive Office organizations, and Congress) are responsible for reconciling demands for funding so that forces, modernization plans, and budgets are appropriately balanced.
- Program management: Program managers are faced with the task of coordinating the activities of all these functional communities whose timely support is necessary for keeping a program on schedule, controlling costs, and attaining the performance objectives.

The interactions among functional communities can be visualized as an iterative process in which risks and uncertainty are systematically reduced through analysis, design, fabrication, and experimentation. Over time, these teams consider options relating to such items as technology, program requirements, and costs—ultimately they converge on a design for a fully developed system (Figure II-1).

The overall goal for acquisition program managers is to structure the development program so as to achieve convergence as quickly and efficiently as possible. These managers must address such issues as:

- How many cycles of exploration are needed to converge to a program design?

- How much time and money is required per cycle?
- How are cycles within and across functional communities to be managed?
- Is the rate of convergence balanced across functions?
- What criteria are used to decide when convergence is reached?

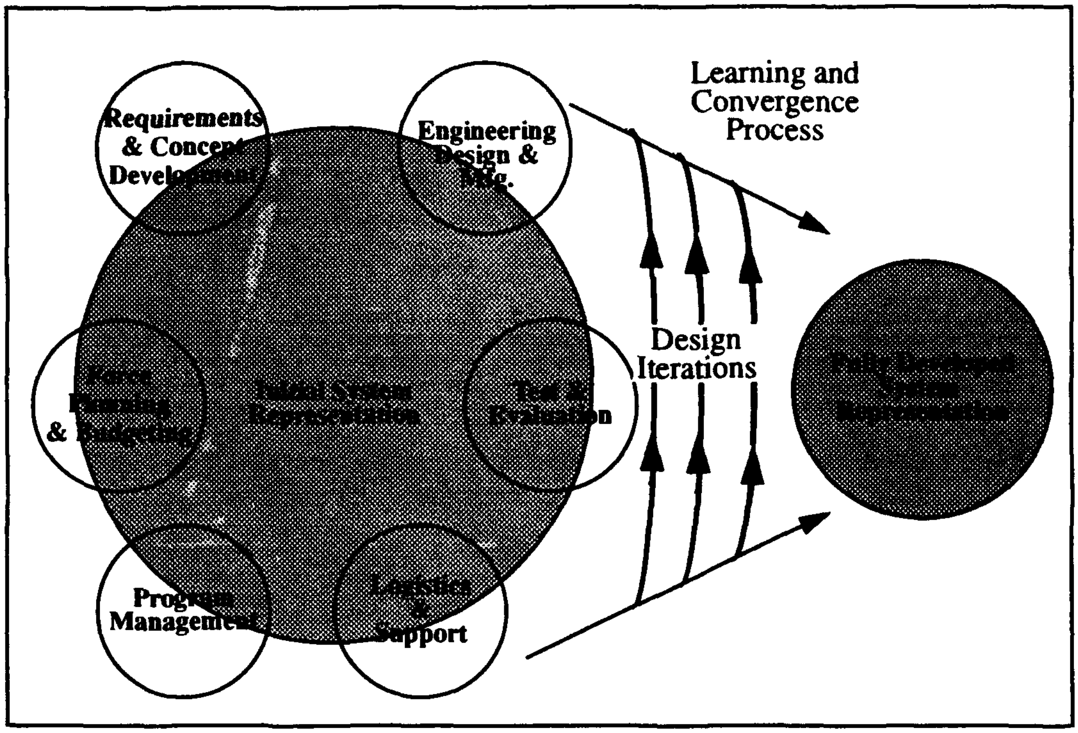

Figure II-1. Convergence in the Development Process

B. NEW MANAGEMENT PRACTICES IN COMMERCIAL FIRMS

In recent years, commercial firms have developed new approaches for the learning and convergence process that have significantly reduced the length and costs of development programs. Their approaches have utilized key concepts that have been variously called concurrent engineering, TQM, enterprise integration, and IPPD. One common goal is to bring the functional communities together from the very outset of a program and thus accelerate the learning and convergence process. An integrated, close-knit team defines the critical design features of a program at the outset, and lays the groundwork for subsequent team coordination. In commercial firms, this entails the teaming of responsible representatives from corporate functional communities, including management, marketing, accounting, and finance, as well as designing and engineering and manufacturing.

Four examples will help to illustrate how these new management practices, key concepts, and advanced technologies have been applied.[1] The first is the Ford Taurus project. Ford formed a multi-functional development team headed by Lew Veraldi, a top Ford engineer, to develop the Taurus. Veraldi set a development goal to be "best in class" for each of about 400 product characteristics, and met about three-fourths of these goals. The Taurus development project took seven years from the decision to develop a new car, five years from the initial sketches, and three years from the board of director's approval of the design [Taub 1991, p. 222]. This was significantly less than typical in Detroit at that time.

The exhaustive study of the Japanese, American, and European auto industries performed by the Massachusetts Institute of Technology (MIT) concluded that automobile manufacturers employing such new advanced management practices, such as used in the Taurus project, are able to design a new model in about three-fourths the time—using about two-thirds the engineering hours—required for traditional design practices [Womack 1990]. Using the terminology developed by the MIT team, "lean design" entails four management principles which provide a good description of concurrent engineering principles:

- Strong project leadership that controls project personnel, budgets, and schedules.
- Project teamwork involving a multi-functional core team of personnel working full time on the project.
- Design team communication that includes clearly defined project performance metrics and milestone exit criteria which are needed to effectively manage risk.
- Simultaneous development that includes creation of production equipment in parallel with the product.

MIT found that successful development programs include an early design phase which involves all of the functional communities in defining critical design parameters. These decisions form the guidance for detailed development work, and for coordinating among the communities as the development project advances.

Lockheed illustrated a similar approach in a space-based system. Lockheed adopted a "skunk works" management approach for its F-SAT (Frugal Satellite) program, headed

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[1] Several earlier examples can be found in Winner [1988]. More recent examples can be found in Nelson [1993] and Heim [1993].

by a strong team leader. Lockheed estimated that this approach reduced development time and costs by 50 percent over comparable programs developed using customary methods. The program director, Gary Turner, attributed his success to an emphasis on direct interaction, and ruthless curtailment of oversight, coordination, and review [Turner 1992]. He emphasized one point in particular: Lockheed co-located, in a single building, a team representing each of the functional communities, including designers, machinists, and cost and financial analysts. At the outset, procedures were established to maximize flexibility in designs and to eliminate bureaucracy. Trial and error and changes were encouraged. Designers could directly mark up blue prints, only three official sets of prints were kept, and one person was assigned responsibility for each drawing.

It is noteworthy that this process worked well without sophisticated information technology. The reason was that team members were able to communicate directly and work with up-to-date paper drawings. The Lockheed experience shows that effective management of the design team and its process is the main requirement for improving the development process.

A third example, the IBM AS400 computer development program, used simulation extensively to augment these management practices.[2] IBM established cross-functional teams that integrated software and hardware design and manufacturing. This integrated approach led to simplified designs and also reduced the part count from 10,000 for the earlier S/38 to 4,000 for the AS400. For software development, IBM broke down the 7 million lines of code into modules which were spread across dedicated software development teams. IBM engineers created a simulator to test alternatives until they converged upon a virtually defect-free design. IBM was able to develop the AS400 in about two years—less than half the time required for its predecessor machine. About 10 months of this 2-year design cycle reduction was due to IBM's use of simulation of hardware design options.

Boeing is currently extending the state of the art in its application of development technology to augment these new management practices with its "paperless" design of the new B-777 aircraft [Lucas 1993]. This is a state-of-the-art application of CAD, CAE, and CAM which is costing over $1 billion to implement. Boeing creates and maintains the design in a computer system consisting of 8 IBM mainframes, 2,200 workstations, and a design application called CATIA, developed by Dassault Systems of France. CATIA allows design engineers to create, configure, specify, and check their parts at their workstations.

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[2] This example is drawn from [Bowles 1991, pp. 163-165].

This system supports 238 functionally integrated "design/build" teams created to design the aircraft. These teams include production personnel, supplier representatives, airline workers, design engineers, and many others.

The B-777 will be the first commercial jet designed entirely on a computer system, not on paper. Boeing will build it without creating a full scale production mock-up. This approach follows that used by Northrop in the B-2 production. According to airplane makers, the single biggest problem in industrial manufacturing is simply parts that don't fit together. Manufacturers have traditionally addressed that problem by constructing a complete full-scale mock-up of a new plane, which is a laborious, time-consuming, and expensive process, just to find out if parts fit. Parts-fit checking for the B-777 is now being done via CATIA. Some subsystems have been mocked-up where CATIA has not been able to mitigate risks. Manufacturing experts are closely watching this project to assess the results of this ambitious experiment.

These examples illustrate, in general, how today's commercial leaders are structuring their development programs and employing new management practices and techniques to speed up the learning and convergence process. In each case there is early, intensive interaction within a multi-functional team, during which major design parameters are analyzed and key decisions are made. The goal is to make change easy during this phase in order to allow as many iterations as possible to be explored. Hence rapid trial and error, feedback, and learning are emphasized and an integrated development is obtained. Where technology is used, it is to support this process. Indeed, new information technologies support such integrated development. Distributed design and engineering simulation tools could, for example, create a virtual co-location for design teams that must remain geographically separated. This approach has allowed such integrated development to be used in large development programs such as the B-777, where literal co-location of the design team was (and remains) impossible.

C. WHY DO THESE NEW MANAGEMENT PRACTICES SUCCEED?

The experiences in the commercial sector provide some important lessons regarding the basic management principles that must be adopted in order to improve the development process. Large corporations contain functional communities that traditionally have had difficulty working together. Designers, manufacturers, marketers, accountants, and financiers see programs from their own perspectives and have difficulty communicating across functional boundaries. Moreover, the loyalty of the design team members to their functional communities often makes it impossible for program managers to exert necessary control across functional lines. The traditional process of sequential or "stovepipe" development causes wasted efforts, rework, and delays. The goal of these new management practices is to eliminate such waste in the development process and other aspects of acquisition.

To help reach the goal, many programs are now structured to overcome two major shortcomings that have plagued large development programs employing a stovepipe development approach. The first shortcoming has been a lack of interaction among the functional communities. Traditionally, this has led to sequential development structures, in which designs are passed from one community to another as the development program progresses. This approach is both time consuming and inefficient. Significant time is lost, for example, when an engineering design is "tossed over the transom" to the manufacturing specialists who must then learn the design and figure out how to manufacture it. Moreover because the designers did their work with incomplete feedback from the production or support communities, their designs may later need to be modified when these communities get their chance to review the designs. Corrections come belatedly as the inputs from other teams and functional communities are received. An important goal of these new management practices is to shorten the feedback loop which in turn accelerates the development process.

The second shortcoming with the stovepipe development approach is a failure to converge on a successful design prior to initiating full-scale engineering and manufacturing development. Given the cumbersome feedback process, the lack of clear risk-management metrics, and the need to keep programs moving, programs frequently begin engineering and manufacturing development before all the technical problems have been recognized and solved. At this stage, the cost of rectifying such problems multiplies. Fixes involve reworking earlier designs, and the coordination cost of these fixes is magnified by the fact that there are large numbers of people doing detailed design work. Because the number of workers involved in a program increases by several multiples when a program enters engineering and manufacturing development, the costs skyrocket for each day's delay caused by technical difficulties.

Both shortcomings—ineffective coordination and incomplete convergence—have caused substantial delays and cost growth in defense acquisition programs. In early program phases, programs are often delayed because of disagreements in defining a program concept (Table II-1). Subsequently, incomplete convergence gives rise to technical problems. Delays in the engineering and manufacturing development phase of a representative

Table II-1. Convergence and Risk Management in DoD Programs[a]

Program Phase	Average Schedule in Months		Reasons for Program Stretch
	Plan	Added Time	
Demonstration & Validation	30 mos.	25 mos.	Lack of Convergence in Program Definition (8 of 11 cases)
Full-Scale Development & Low-Rate Initial Production	51 mos.	33 mos.	Technical Difficulties (20 of 27 cases) Lack of Convergence in Program Definition (5 of 27 cases)

a. Source: [Bicksler 1991].

sample of recent programs added 60 percent to planned development times. Required budgets were also increased: at least one-third of the programs required more than twice as much development funding as initially planned.[3] New management practices and development technologies that help to identify and eliminate these technological problems prior to entering engineering and manufacturing development could significantly reduce program schedules and costs.

NASA found a similar pattern in reviewing the history of its major programs. When initial design phase investments were correlated with subsequent cost and schedule performance, they found that programs experienced far less cost and schedule growth when a greater share of program resources was devoted to the initial design process.[4] NASA thus concluded that significant program cost savings—roughly 25 percent of program development costs—could be obtained by ensuring that adequate design convergence is achieved before full-scale development begins.

These new management practices (especially concurrent engineering) entails a new structure for managing development programs. Somewhat more effort is to be expended earlier in the development process, when a multi-functional team defines the main program

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[3] These schedule slippages and funding increases represent a snapshot of a sample of programs within the engineering and manufacturing development phase at the time the study was conducted. Many of these programs did experience even further slippage and funding growth (beyond that reported in the source document) before completing the development phase. See Bicksler [1991].

[4] NASA found that programs that invested 5 percent of planned program funds in the initial design phase (phase A/B in NASA's terminology) had subsequent overruns averaged 30 percent. When 10 percent was invested in this phase, program overruns were only 5 percent [NASA 1992].

development parameters (Figure II-2). Most of the design effort is accomplished during the initial design phase. Less effort is required for design modifications, and because risk is managed better, substantially less redesign is required for engineering changes during full-scale development. Fewer total engineering hours are required, and the development time is substantially reduced.

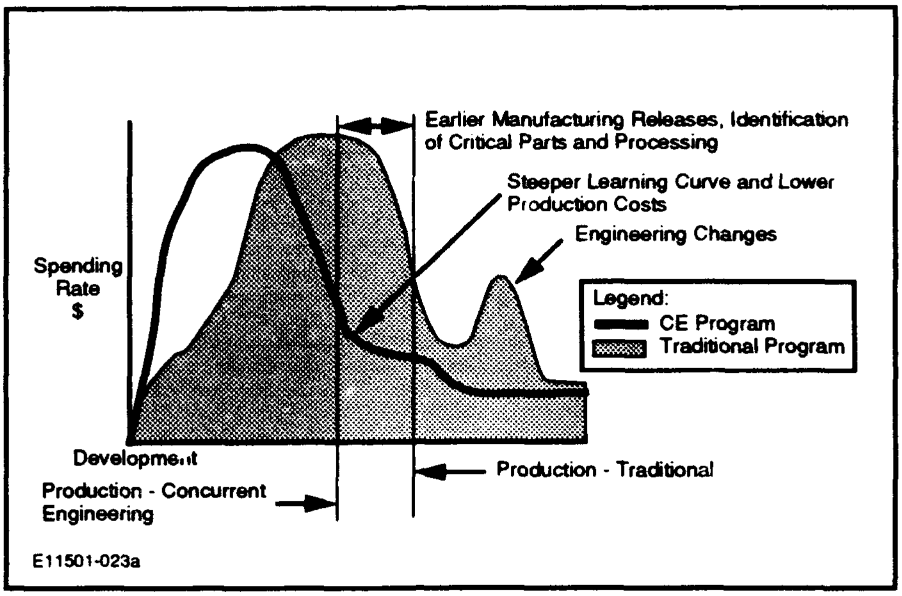

Figure II-2. Restructuring the Development Process
Source: LaBauve [1992, p. 28]

As experience is gained with these new management practices, the reasons for their success are becoming clear. By using these practices, companies have been able to accelerate the cycles in the iterative process of analysis and experimentation, which allows the functional communities to converge more quickly on a design. The practices also allow rapid consideration of many options within each functional communities, and facilitate communication across functional communities. A corollary benefit is the improved management of risk within this process. With enhanced communication among participants, problems or risks surface much earlier and can be resolved before major additional expenses are incurred.

D. THE ROLE OF DISTRIBUTED SIMULATION

Leading commercial firms are exploiting simulation capabilities to augment these new practices to further streamline and accelerate the design convergence process in developing new products. Within appropriate management structures, commercial companies have used simulation to contribute to:

- Faster cycles of analysis and experimentation within each functional community.
- Faster and clearer communication across functional communities.
- Clearer understanding of and consensus on major design parameters.
- Improved understanding and management of risks.

For many readers of this paper—those with the benefit of hindsight and a perspective from outside of the organizations involved —these management practices may seem obvious and straightforward to apply. However, the changes needed in their adoption are very difficult to make because they threaten existing organizational cultures and hierarchies. The DoD acquisition community faces even greater barriers than faced by commercial firms: traditional cultural and organizational barriers are at least as daunting within the government as in the commercial world; there are significant legislative and regulatory barriers imposing arms-length checks and balances within the government that make it difficult for communities to work together; and the DoD lacks the profit-loss incentive of the competitive marketplace which has strongly motivated commercial organizational and management innovation. We will return to these issues in the final section when we review the experience of some commercial firms in implementing these new practices, and consider some of the issues that the DoD will have to address in adapting those practices and distributed simulation to defense development acquisition.

III. DISTRIBUTED SIMULATION IN DOD'S DEVELOPMENT PROGRAMS

The degree to which distributed simulation can support acquisition programs within DoD—both today and in the future—depends on the power and acceptance of the available distributed simulation tools. These can be measured in terms of the degree to which available tools provide the four capabilities outlined in the introduction: visualization, performance modeling, common information base, and user interaction. To gain an understanding of available simulation technologies, this section examines the current state of the art and the potential future application of distributed simulation in defense development programs.

In this paper we consider three general levels of distributed simulation, which represent the increasingly powerful tools that will be available to support the DoD acquisition processes. These simulation technology advances are:

- *Functional distributed simulation:* Provides visualization and performance modeling within a functional community. Most current simulations are of this type.
- *Cross-functional distributed simulation:* Provides common data and user interaction across some functional community boundaries and permits some enhanced functional capabilities. Limited cross-functional capabilities also exist today.
- *Functionally integrated simulation:* Represents the long-term vision in which distributed simulation would eliminate the language barriers across and within all of the functional communities. This would permit engineering designs to be reviewed and evaluated by the communities by using their customary analysis tools and utilizing an enterprise information network connect with common information bases.

We shall begin by describing the current status of distributed simulation within each of the six functional communities, and then review simulation's role in improving cross-functional communication and coordination. Examples based on site visits, interviews, and available reports illustrate how distributed simulation has been used. These examples do not represent an exhaustive review, but we believe they provide a representative view of the kinds of simulation capabilities that are in use.

A. SIMULATION WITHIN FUNCTIONAL COMMUNITIES

Simulations within individual functional communities include those that offer visualization and performance modeling capabilities for a single functional community, without necessarily providing information which automatically/electronically passes through networks which crosses functional lines. For example, wind-tunnel simulations assist engineering designers in creating new wing designs. Combat simulations allow concept developers to examine effectiveness in a combat environment. Such tools permit each community to do its work faster, thus contributing to an acceleration of the learning and convergence process. These advances have been spurred by the continuously expanding capabilities within computer hardware and software disciplines.

These kinds of simulation tools already are common within each of the DoD's functional communities. Since each community has a unique focus, the tools they have developed tend to be specialized. Such simulation tools generally fall into one of four families:

- The *combat* performance simulations used mostly by concept developers, trainers, testers, and force planners.
- The *physical* simulation exemplified by performance models, engineering simulations, and process models which are used mostly by designers, engineers, and manufacturers.
- *Availability and support* simulation models used mostly by operational and logistics planners.
- *Cost and schedule* models and simulations used mostly in budgeting as well as in structuring and managing programs.

The nature and role of simulation will therefore differ across functional communities and families of simulation (Table III-1). The appropriate role of the human in the simulation varies depending upon the application because not all functions require manned simulations to address their concerns. But in some areas, particularly requirements and concept development and test and evaluation, the ability to conduct manned simulations is essential. The role of simulation in each of the functional communities is discussed in turn.

Table III-1. Examples of Simulations Used Within Functional Communities

Functional Community	Simulation Tools (Simulation Family[a])	Simulation Examples	Program Examples
Requirements and Concept Development	System, unit, and force-level effectiveness (combat)	SIMNET	M1A1
	Military worth (combat)	Domed Flight Simulators	AMRAAM, F-15, F/A-18, F-22
Engineering Design and Manufacturing	Physical performance (physical)	IBM	AS400
	Human factors (physical)	CATIA	B-777
	Manufacturability (physical)	Northrop	B-2
Test and Evaluation	Physical performance (physical)	SIMNET	FAADS, ADATS NLOS/FOG-M
	Operational effectiveness (combat)	Domed Flight Simulators	F-22, F/A-18, F-15
Logistics and Support	Reliability (physical)	RAMCAD	B-52, M109
	Support requirements (availability and support)	Logistics Capability Model (LCAM)	F-22
Force and Budget Planning	System, unit and force-level effectiveness (combat)	TACWAR JANUS	FOFA/ATACMS FOG-M, NLOS, M1A1
	Resource planning (cost and schedule)	FACS	Numerous Programs
Program Management	Program structure Cost estimation	IDEF, FORESIGHT	MUAV/VTOL-UAV
	Program management (cost and schedule)	Parametric cost models	

a. The simulation families are defined in the text, Section III.A.

1. Requirements and Concept Development

Simulations have been and are being used extensively in defining concepts in some warfare areas. They support the demonstration of new technologies, concepts, and tactics, and they support the analysis of man-in-the-loop design factors.

The premier applications are in air-to-air combat. One noteworthy example is the operational utility evaluation conducted for the AMRAAM missile in the early 1980s.[1] At that time, AMRAAM was a conceptual design for a long-range, fire-and-forget air-to-air missile. There was some question as to whether such a missile would be operationally effective, given the problems in identifying friend vs. foe aircraft at beyond visual range. To address these concerns, an extensive simulated operational test of the AMRAAM was conducted using domed flight simulators at McDonnell Douglas. Simulations were conducted because the cost of live tests was prohibitive. The simulations included red and blue teams of aircraft. Pilot's tactics evolved rapidly as they gained experience in using and eluding the missile, illustrating the importance of manned simulation in concept development. The tests concluded that the missile was useful but mostly because of its fire-and-forget features rather than its long-flight range. The tests also uncovered problems with the AMRAAM seeker that eventually were worked out in engineering development.

Air-to-air simulators have also been used extensively for the F-15 and F/A-18 programs at McDonnell Douglas, and they play a significant role in the ongoing F-22 program as well. Two factors have contributed to the success of simulation in the air-to-air warfare area. The first is that simulation technology is well developed and accepted because of its long-standing use in the training community. The second is that such applications involve a rather simple environment to model, and can be meaningfully undertaken with relatively few simulated weapons.

Much attention is given today to attempts to extend manned distributed simulation to the ground combat environment. One example is presented by the defense Simulator Network (SIMNET) studies in helping to establish the requirements for the M1A2 tank [USA 1988]. A recent Defense Science Board study [DSB Sim 1993] estimated that such simulations provided order-of-magnitude savings in concept development over traditional development methods.[2] In the mid-1980s, a live test of possible upgrades of the M1 loader

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[1] Private communications with Mr. John Shea, Institute for Defense Analyses, Alexandria, Virginia, and Mr. Harry Passmore, McDonnell Aircraft Company, St. Louis, Missouri.

[2] This example is based on the DSB study cited. Costs are the marginal costs of conducting the tests and simulations, and do not include the costs of developing the simulators.

and fire-control systems took two years and cost $40 million. Despite those costs, only one design alternative was able to be tested. Subsequently, a 1986 test using modified aircraft dome simulators allowed a single version of an M1A2 configuration to be simulated in six months at a cost of $1 million. By 1992, with the availability of SIMNET, it was possible to examine four variations of the M1A2 design in only three months at a cost of $600,000. The SIMNET simulations played a substantial role in defining the concept for that program.

Other examples, such as the use of the Theater Air Command and Control Simulation Facility (TACCSF) for early proof of principle tests for friend vs. foe identification, suggest that these simulation methods may be applicable for command and control systems as well. These examples, while selective, show the extensive use already being made of simulation in setting and defining program concepts and requirements.

A key problem in the establishment of the requirements has been the mutual acceptance of the measures of performances that are to be used throughout the life of the program. Those measures should be established and used in each of the functional communities to conduct such efforts as formulating the design, conducting the cost and operational effectiveness analyses (COEAs), and evaluating the design during tests and evaluations

2. Physical

Performance, engineering, and process models and simulations are extensively used within the engineering and manufacturing communities. Commercial software developers are creating a wide range of engineering simulation tools that allow engineers to simulate different concepts and designs.[3] They allow the physical characteristics of designs to be modeled and simulated. Stress analyses, heat transfer, electromagnetic properties, and dynamic properties of components can now be examined. These software packages can directly read by standard CAD/CAE data bases.[4] In many cases, manufacturing process engineers can tap into these data bases and examine manufacturing process issues using

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[3] The design and engineering software packages currently available include modules for high-level concept development and detailed engineering design. Many include internal analyses tools such as stress analysis. Many provide, as options, modules that permit manufacturing process design issues to be addressed. The design data bases can also be exported for use in engineering simulation models.

Some of the brand names in design and engineering tools that are currently on the market include the following: Intrgraph's MicroStation, CADKey's CADKEY, Autodesk's AutoCAD, Computervision's Personal Designer, and Adra's CADRA-III. A rapidly growing competitor is Parametric Technology's family of tools including PRO/Design, PRO/Engineer, and a range of manufacturing application tools. Other major names include IBM's CADAM, the Manufacturing and Consulting Service's ANVIL-5000, and Dassault's CATIA.

their own simulations. Applications of these technologies by IBM and Boeing were described in the second section. Current technology thus permits extensive interaction among concept designers and product and process engineers, supporting the implementation of the principles of these new management practices.

The use of these engineering tools is also commonplace among defense firms. One well-known application illustrating the state of the art is Northrop's extensive simulation of the B2 structural designs. Northrop credits its simulation activities with allowing it to skip the usual full scale production mock-up and still fabricate complex components with no scrap or rework [Winner 1993].

Engineering design and manufacturing represents the most mature application of simulation tools of all DoD's functional communities. It also is an important example of dual use technology. Advances have been driven by commercial developers who continue to improve the available tools and data. The DoD needs to keep abreast of commercial developments and adapt them as needed for application in defense programs.

3. Test and Evaluation

Simulation has long been used within the test and evaluation community to complement traditional tests. Engineering simulations of physical characteristics support developmental testing, which is performed in the design and development phase of system acquisition. They evaluate the designs by addressing the total system, subsystems, parts, and components. They also seek to demonstrate actual performance. Combat simulations help guide and augment operational tests, and help incorporate human factors. Operational testing is conducted to determine the operational effectiveness and suitability of a system under realistic combat conditions. Because of the very nature of operational testing, virtual or constructive simulations cannot fully replace live testing. Nevertheless, simulation has an important role. The application of distributed simulation in each of these phases of testing is discussed below for both developmental and operational testing.

Engineering simulations are commonly used in developmental testing and evaluation. Some examples include wind tunnel models; mobility models; reliability, survivability, and maintainability models; and human factors and control models. Various component

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[4] A leading supplier of such modeling tools is the MacNeal-Schwendler-Aries team, which offers the ConceptStation design system and modeling tools including MSC/NASTRAN, which performs structural and heat transfer analysis; NSC/EMAS, which performs electromagnetic analysis; and MSC/DYTRAN, which conducts high-speed fluid-structure interaction analysis. This later analysis is used, for example, to model the effect of bird strikes on aircraft engines and canopies.

simulations (such as missile fly-out models) are used in system testing to reduce costs. Used in conjunction with developmental testing, these tools can significantly reduce the time and cost required to demonstrate the physical performance of new systems and their components.[5]

The role of simulation changes somewhat as testing transitions from developmental to operational issues. In operational testing, simulations based on developmental test results are used to design and evaluate tests, and to overcome the limitations and constraints of a field test environment. Several examples illustrate the applicability of simulation in operational testing. The manned simulators at McDonnell Douglas's domed flight simulation facility were extensively used in developing better operational testing scenarios in developing the F-15 aircraft. Simulation of F-15 flight tests helped considerably in designing specific details of actual flight tests, as well as in constructing the overall matrix of flight tests needed to address design uncertainties.

An appreciation of the role that simulation can play in improving cost effectiveness in testing is provided by comparing the resources expended during the planning and then the execution of the developmental testing for the Forward Area Air Defense System (FAADS). Constructive simulations using JANUS helped to establish the key performance measures, then distributed simulations using SIMNET helped to plan the actual tests, and then less expensive (than initially planned) field tests were conducted. Considerable resources can be saved with effective planning using models or simulations to complement field test time[6] (Table III-2).

Table III-2. Resources Expended in Planning and Execution of FAADS Field Tests

Phase	JANUS Man-Days	SIMNET Man-Days	Field Test Man-Days
Preparation	21	46	2,345
Exercise	105	550	5,067[a]
Analysis	74	25	600
Total	200	621	8,012

a. Includes extensive reliability and specified stand-alone tests

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[5] Ford Motor Co.'s Howard Crabb, manager of computer-aided engineering (CAE) for Ford's Alpha design division, estimates that use of the "ConceptStation solid modeling CAE tool combined with MSC/NASTRAN has reduced the cycle time for designing components by 40% to 70%." (See [MacNeal 1992].)

Another important application is in the ongoing development of test plans for the F-22. The Air Force presently is conducting an 18-month study to determine the appropriate set of tests for comparing the effectiveness of the F-22 against the F-15 [USAF 1992]. These tests will occur as part of the F-22 OT&E. This study is relying on a combination of the TAC BRAWLER air combat model and exercises using Lockheed's domed simulator facility. Hundreds of model runs will be undertaken to identify the parameters that best discriminate the performance of the comparison aircraft. Domed simulations will then focus on the effect of varying assumptions about this set of variables and determine measures that best define "mission success." The domed simulators will be calibrated when data become available from the early flight tests, so that the simulators can be used to extrapolate to environments that are not feasible in the live tests (e.g., higher density threat environments).

As we have shown, simulation plays important roles in both developmental and operational test, and its contribution will increase as simulation technology advances. However, simulation can never be expected to fully replace the need for real tests. Simulation—like other performance modeling tools—is limited by the range of experience embodied in its analytical structure and data bases. There are valid concerns about such data issues as being able to get wide acceptance of data from manned simulations, being able to validate results of simulations versus data from test ranges, and being able to extrapolate with some degree of assurance from the simulated test environment to other environments. Simulation will be useful for extrapolating to new designs, environments, and scenarios in some cases, but in other cases extrapolation errors may invalidate the results. This question of extrapolation error is at the heart of the VV&A of simulations, and it is also the key limiting factor in its use for developmental and operational testing. Although simulations are designed to capture known physical principles, DoD development programs are often designed to push the envelope of well-known technology. Hence, there will nearly always be some uncertainty and risk of extrapolation error when new development programs are simulated. Nevertheless, as the preceding examples show, simulation used in conjunction with testing is a powerful development tool.

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[6] In a similar example, SIMNET was used in evaluating ADATS test range results to show that simulation was able to predict the major measures of performance. This test suggests that SIMNET could usefully be applied in designing subsequent tests. If a simulation can lead to the same general conclusion as a test and identify the factors driving the results, then simulation can provide an important tool for early operational assessments. Similarly, simulation may be useful in augmenting test data that was limited by safety considerations, expense, availability of test ranges, or weather. All in all, the use of simulation can complement testing, making testing more effective and economizing to some degree on the expense of field tests.

4. Logistics and Support

The capabilities that are being developed to strengthen analysis of logistics and support issues fall into two main categories. The first are those that are bringing reliability and maintainability concerns within the engineering environment. Among these is the Continuous Acquisition and Life-cycle Support program (CALS), formerly called the Computer-Aided Acquisition and Logistics Support program. Although CALS is not itself a simulation tool, its goal is to create the data bases that would also be used in simulating support issues as they relate to the design process. It currently includes three main activities:

- Accelerating the introduction of reliability, maintainability, and supportability considerations into the computer-aided design process.
- Enhancing the capabilities within defense industry to supply technical data to the government in digital form.
- Enhancing the capabilities within the government to properly receive and use these data.

CALS data exchange standards are now important vehicles for the management and distribution of maintenance "tech data."

An initial thrust of CALS is RAMCAD (Reliability And Maintainability in Computer-Aided Design). It focuses on the use of computer-aided design technology to continually assess and improve the reliability, maintainability, and supportability characteristics of a product throughout the design phase. The current focus of RAMCAD is on:

- Improving methodologies for incorporating support issues in design analysis.
- Improving methodologies to conduct tradeoffs among support measures.
- Improving methods to allow tradeoffs among the different engineering disciplines.

The second kind of logistics simulation capability employs reliability and maintainability statistics to estimate support requirements. For example, the Air Force is using the Logistics Capability Assessment Model (LCAM) to estimate the logistics support requirements for the F-22 aircraft. This model employs Monte Carlo techniques to simulate component failure rates in estimating maintenance manpower and spare parts requirements.

It is apparent from these examples that extensive efforts are underway to gain not only better understanding of the logistics capabilities and deficiencies but also to incorporate them into weapon support considerations within the design process. This is one area where the acquisition community has clear responsibility for investments in technology, and this should remain a focus for future efforts.

5. Force Planning and Budgeting

The DoD has relied extensively on models and simulations in its systems analysis approach for evaluating force structures and for planning force modernization. Many theater-level models and simulation tools are in use today to assist in designing forces and planning for modernization. These plans underlie the development of DoD budgets even when they are not used directly in the budgeting process. One good example is the modeling done in the 1980s in creating the deep strike, follow-on-forces attack (FOFA) modernization strategy within the Office of the Secretary of Defense (OSD) and the Army. Extensive analyses considered force structure options for deep attack weapons and their appropriate balance with direct fire weapons. This kind of analysis is commonly conducted to establish force structure requirements for new systems.

The Advanced Research Project Agency's (ARPA) recent WAR BREAKER demonstration is a good illustration of how distributed simulation could be used to address future force planning issues. WAR BREAKER has demonstrated how Army, Air Force, and Navy sensors, command, control, communications, and intelligence (C3I), and weapons systems could be teamed to attack critical mobile targets. In this demonstration, existing systems were considered to test the feasibility of the simulation network itself. But the demonstrations suggests how, in the future, different mixes of current and proposed systems, along with new tactics and doctrine, could be explored in the simulation environment. Analyses of this kind bridge the gap between the concept development community and the community of force planners and budgeters.

WAR BREAKER's distributed simulation network plows new ground in permitting the military to explore combat approaches involving seamless, multi-Service, "system of systems" approaches for performing future military tasks. Modernization planning will increasingly have to address these complex "system of system" issues because limited DoD modernization budgets will have to focus on finding investments that enhance the capability of current platforms. The role of distributed simulation in force modernization planning is thus likely to expand as rapidly as the simulation technologies permit it.

Complementing these force-level combat simulations are force costing models such as the Force Acquisition Cost System (FACS). These allow DoD resource planners to estimate total program costs and budget requirements for force options. Costs include research and development, acquisition, and operations and maintenance. When such models are combined with force effectiveness evaluation models, such as TACWAR, additional options for program and force structures can be considered. Such assessments provide useful support in evaluating broad tradeoffs in designing modernization programs.

Force planning and costing simulations could offer an important bridge between the communities involved in requirements setting, force planning, and budgeting. The acquisition community can play a significant role by ensuring that future models and simulations are compatible across these communities. We will return to this question when we take up the issue of how simulation is supporting cross-functional integration.

6. Program Management

Traditionally, program management simulations of costs and schedules have been an important tool for planning and executing major weapon programs. Cost modeling has, of course, been done extensively within the DoD for decades. Parametric cost models, based on historical statistical relationships, provide estimates of likely program costs.

Similarly, program planning and process models have long been used to structure and sequence program tasks. Their use stems back to the creation of the Project Evaluation and Review Technique (PERT) developed for the Navy's Polaris program. One recent application of process modeling is in an ARPA program which studied the Vertical Takeoff and Landing - Unmanned Aerial Vehicle (VTOL-UAV)[7] program. The FORESIGHT process modeling tool, an extension of IDEF[8] concepts, was used to help structure the tasks required to conduct a planned exercise, as well as to surface issues and problems that might not otherwise have been anticipated.

There are many new management practices that have been developed and applied in various levels of detail within several programs. The F-22 program is representative in its attempts to include the key features of concurrent engineering and TQM concepts. They have organized cross-functional teams, have made the industry contractors an integral part

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[7] Previously called the Maritime Unmanned Aerial Vehicle (MUAV).

[8] The acronym IDEF originally stood for the ICAM Definition language. ICAM (Integrated-Computer Aided Manufacturing) was the sponsoring organization within the U.S. Air Force for the original IDEF development efforts. More recently, the Information Integration for Concurrent Engineering (IICE) Program has assumed responsibility for the continued development of the advanced methods of IDEF. The IICE Program now refers to IDEF as the Integrated Definition Language [Rupp 1993, p. 328].

of the program decision-making process, and have developed measures of performance for many key activities [Winner 1993].

These cost and schedule simulation tools represent an interesting extension to the current parametric approaches. On the one hand, the use of parametric cost models and program planning simulations are among the most mature applications of modeling and simulation among those in use today. But, on the other hand, the application of these tools will be subject to the greatest change as new development practices are adopted. Whereas these tools have traditionally been used to extrapolate costs and schedules from past experience, in the future they will be used as a guide to re-engineering the development process. New process simulation tools will permit managers to consider optional structures for programs. The results of one of the DARPA Initiative on Concurrent Engineering (DICE) programs provide an illustration of how process modeling could be used to restructure the development process to perform tasks more effectively [Singh 1992, pp. 14-23]. One effort within GE Aircraft Engines reduced the development cycle time from 18 months to 7.5 months while at the same time increased the number of design iterations (improving the quality of the design) from 11 to over 60. In time, such process models should become a routine tool for implementing concurrent engineering practices in DoD programs.

7. Conclusions Based on Functional Review

The examples presented in each of the functional communities demonstrate the wide range of applications of simulation in the defense acquisition process. In one form or another, simulation is used by every one of these communities. The maturity of the applications varies substantially across functional communities, across simulation families, and within the functional communities. In part, this reflects the fact that engineering simulations have largely been developed in the private sector, and the other functional simulation technologies have largely been developed by the communities that use them. There has been little incentive for establishing commonality in modeling and simulations designs or data formats.

Advances in technology, data, and applications will occur in every functional community, so the contribution of simulation will grow. These advances suggest that simulation will contribute to improvements in the learning and convergence process within functional communities, independent of DoD's investment or in its progress in adapting commercial development approaches. However, as the commercial experiences reviewed in Section II have suggested, the use of new management practices and the utilization of simulations could make a significant contribution if it were used to support integrating activities across the function communities. Such applications are discussed in the next two subsections.

B. CROSS-FUNCTIONAL DISTRIBUTED SIMULATION

We noted in the introduction to Section III that the simulation tools used in defense acquisition fall into four families: combat, physical, availability and support, and cost and schedule. This subsection examines the degree to which there is common uses of simulations within similar families and across the functional communities. Such commonality could be the basis for integrating future development activities within those communities.

We find there is considerable overlap across communities in the use of simulation, suggesting that simulation tools could provide a common ground among communities. We have identified where each family of simulation is used by nearly all of the six acquisition functional communities, and each community uses nearly all of the families of tools (Table III-3). In practice, however, the degree of integration afforded by this overlap is limited by the lack of compatibility among simulation tools within each family. Some examples are presented in this section to illustrate the current state of the art.

1. Combat

The first row of the table summarizes the various applications of combat simulations in the six functional communities. The McDonnell Douglas domed flight simulator facility provides an excellent illustration of how a simulator could be used in the first, second, and third communities. First, the AMRAAM simulations described earlier illustrate the use of that facility in defining concepts and setting requirements. The domes have also been used for engineering studies, particularly when human factor aspects are being defined. They have been used extensively for cockpit design layouts, for example, and presently are being used to evaluate different configurations of the MIDS aircraft data terminal for the F-18 aircraft.

These simulators have also been used to design and augment operational tests, for example, in the extensive use of the simulators during the F-15 operational tests. McDonnell's domed simulators generally have not played directly in force planning analyses because they assess few-on-few, rather than force-on-force engagements, and thus do not capture the breadth of engagement needed for force planning. However, the WAR BREAKER demonstration cited earlier provides an interesting counterexample because it incorporated McDonnell's F-15 simulator in a SIMNET distributed network simulation to assess system compatibility, command and control operations, and system performance. In sum-

Table III-3. Examples of Common Simulations Used Within Each Simulation Family and Functional Community

Family of Simulation	Uses by Functional Community					
	Requirements & Concept Development	Engineering Design & Manufacturing	Test & Evaluation	Logistics & Support	Force Planning & Budgeting	Program Management
Combat	Requirements & Concepts	Human Factors	Operational Test Design	Support Alternatives	Force Planning	Organizational Structure
Physical	System & Subsystem Trade-offs	Detailed Design & Mfg. Process Design	Developmental Test Design	Reliability & Maintainability Assessments		
Availability & Support	Availability of Systems & Supplies	Design Trade-offs	Developmental Test; Operational Test	Logistics Planning	Contingency and Operational Needs	Organizational Structure
Cost & Schedule	Cost & Performance Trade-offs	Cost & Performance Trade-offs		Cost & Performance Trade-offs	Budget Planning	Cost & Schedule Planning Management

mary, there is a high degree of overlap of interests across functional communities in the use of a combat simulation capability such as exists for the F-15.

The WAR BREAKER example points to the earlier observation that there are significant differences across communities in the type and the level of detail of the simulation tools used. For example, the detail required to model and simulate theater-level combat support force planning is quite different from the detail required to support the development of a manned weapon system or to study the effectiveness of a sensor concept within a complex set of environmental conditions and scenario variations. Moreover, existing simulators employ different software and data. A major challenge of the WAR BREAKER demonstration was simply to connect diverse simulators. While each community may have a different set of expectations of the level of detail or the type of simulation required for its application, a common basis should be sought for developing and using simulations within a given family. As simulation technology advances, it should be used to provide a common basis for the analyses conducted within each community, and to provide an effective channel of communication among the communities employing combat simulation.

2. Physical

Whereas the domed simulators provide a common simulation medium across several communities, there is a wide range of types of physical simulators used in acquisition programs. Recognizing this, the engineering community has initiated efforts to provide a common language that will integrate these physical simulators. Such activities will serve to increase integration within the engineering and manufacturing community, as well as to include logistic support issues within the development process. Foremost among these is the support of the Departments of Defense and Commerce for a product data exchange standard (PDES) which would allow commercial development tools and simulators to exchange information. A universal language for engineering design tools could allow any of the tools within the engineering, manufacturing, and support families of simulation to work together. This would greatly facilitate the creation of integrated design teams involving members that formerly were separated by their use of disparate engineering tools.

The integration of logistics, support, and analysis data bases with design and engineering data bases has, of course, been an explicit goal of the DoD's CALS program since the mid-1980s. New acquisition programs are required to meet CALS data exchange standards, and this is helping to create the needed bridge. The RAMCAD program is also striving to integrate support considerations within design and engineering tools. A key limiting aspect on integration across organizations within this family are proprietary and personnel sensitivity concerns. Appropriate security safeguards are needed to help ensure vested ideas, concepts, and limitations are adequately protected.

3. Availability and Support

The concern for weapon system availability and support has led to the development of a large number of models and simulations. The requirements and concept development community has used these models to help define specifications and evaluate new design concepts and approaches and to plan for a weapon's logistic support. The engineering design and manufacturing communities use these types of models and simulations as they iterate on design, producibility, and support issues.

Detailed component studies of electronic parts and mechanical interactions have been the basis for many engineering and manufacturing efforts. Many simulations model the mean-time-between-failure and mean-time-to-repair of both mechanical and electronic components. The RAMCAD efforts mentioned earlier support these and other analyses.

The LCAM gives estimates of the logistics support needed for new aircraft. Similar simulations give insights to the needs for ground vehicle and water craft.

4. Cost and Schedule

Presently, cost and schedule models and simulations remain largely unconnected with the other families of simulators. In the future, however, the ability to simulate the development process using IDEF, or other similar tools, should integrate costs and schedule estimation with the engineering development tasks, thus permitting more accurate estimates to be made of costs, schedules, and risks.

The needed linkage between engineering, manufacturing, and support simulation and cost estimation is being forged through the development of activity-based cost (ABC) accounting [Drucker 1990, p. 97].[9] ABC focuses on allocating both direct and overhead costs to identifiable activities, rather than simply treat overhead as a loading factor on direct labor hours. Allocating costs to these activities gives management a clearer, and very different, view of costs than is provided by conventional cost-allocation methods [Cooper 1991, p. 132]. In time, the emerging design and engineering tools will provide the activity-based data needed to estimate costs using ABC principles, and this in turn, will provide better estimates of costs as well as better insights into the design of manufacturing processes [Dilts 1990, pp. 50-53].

In summary, limited capabilities presently exist for using simulation to communicate across functional boundaries. These communication "bridges" operate mainly in two areas: first, in programs where a common combat simulation can be used for requirements determination, operational test planning, and force planning; and second, where there are programs whose engineering data are used in manufacturing and support communities. Substantial efforts already underway further break down the barriers within and across families of simulation. These efforts should be expanded and include the development of an overarching architecture for the functional communities and/or family areas. Particular emphasis should be placed on defining the interfaces between the functional communities

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[9] Peter Drucker observes that current accounting practices evolved earlier this century, when direct blue collar labor accounted for 80% of all direct manufacturing costs. Drucker notes that a consortium of automated equipment manufacturers has spearheaded the development of new cost accounting methods, because traditional methods could not adequately measure the benefits of investments in new manufacturing technologies. This consortium is Computer-Aided Manufacturing-International, CAM-I.

for each family. These need continued support from the DoD. The DoD should work to also build bridges among the DoD's simulation families, and between them and the commercially developed design tools and simulations. This is an area where the defense acquisition community has a central responsibility, and where progress is unlikely to occur without support from senior DoD leadership.

It will be necessary to bridge the very detailed descriptive and physical performance data that exists in the engineering environment with the more macro performance data that are used as inputs in combat or cost and schedule simulations. Because of the complexity of this task, it will probably be many years before automated data exchanges among these families of simulation will be possible.

C. THE VISION: A FUNCTIONALLY INTEGRATED SYSTEM ACQUISITION PROCESS

The ultimate goal of efforts to integrate development tools is to extend simulation capabilities—visualization, performance modeling, common data, and user interaction—seamlessly across functional boundaries. A fully integrated simulation system would provide each community access to a common data base, and allow each community to visualize and understand the design and its capabilities from its own perspective. For example, concept designers could view a design in a simulated combat environment. Testers would see it in a lab or on a test range. Manufacturers could see it in the context of a simulated manufacturing system. Logisticians could see it in terms of reliability statistics, individual repair tasks or unit-level support requirements, or theater logistics flows. Full integration of distributed simulation capabilities should substantially reduce the communications barriers among acquisition functional communities. It should also improve risk management, by allowing each community to visualize a design in the context that best allows them to anticipate issues and problems.

Functionally integrated simulation capabilities will help fulfill the vision of "agile manufacturing" and "agile logistics." Agility refers to the ability of suppliers to rapidly and cost effectively respond to customer's needs.[10] Agility incorporates five main elements which rely heavily on distributed information technologies:

- Electronic links among customers, designers, and suppliers.

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[10] Here we use *supplier* and *customer* in the broadest context and as used in TQM applications. Also see [Lehigh 1991; Port 1992].

- Electronic data interchange (EDI) among suppliers, allowing design and engineering data to flow among them.
- "Virtual companies" consisting of teams of key marketers, designers, and suppliers from diverse organizations that can be formed and dissolved as needed to meet market demands.
- Flexible manufacturing allowing each supplier to rapidly adapt its product line to satisfy customer demands.
- Express distribution allowing components to flow quickly among suppliers and finished products to quickly reach customers.

The long-run vision for an agile manufacturing sector would include an information "highway" that could be accessed by customers, designers, and suppliers; engineering data bases to support rapid product development; and common data standards and languages that would permit easy communication. The role for distributed simulation technologies in this concept is to enhance communication across organizations with different functional perspectives. It provides the needed common language and visualization that would allow the interconnected entities to communicate effectively. This vision provides a starting point for defining the DoD's long-range objectives for simulation-related programs and policies and achieving a functionally integrated system acquisition process.

D. CONCLUSIONS OF FUNCTIONAL AND CROSS-FUNCTIONAL REVIEW

Our review shows that simulation tools and applications are quite advanced in some application areas, as for example in the use of domed flight simulators for aircraft engineering and manufacturing development, and testing and evaluation. Computer-aided design and engineering tools are also rapidly developing, allowing a range of components to be represented and their physical characteristics modeled. The underlying base of detail design, environment and scenario data, behavioral models, and model validation procedures remains sparse, but will grow as new applications are undertaken.

Thus distributed simulation is becoming a reliable tool for developers in many applications. However, it is only beginning to provide capabilities for communication across functional areas. We conclude, therefore, that considerable further development of simulation tools, with a focus on cross-functional integration, will be required before distributed simulation can fulfill its promise of supporting an integrated acquisition process.

IV. TOWARD AN AGENDA FOR APPLYING DISTRIBUTED SIMULATION IN THE ACQUISITION PROCESS

Commercial experience suggests that improvements in the DoD's acquisition process will require a combination of both investments in simulation capabilities and implementation of management initiatives aimed at establishing a functionally integrated acquisition process. This section describes the building blocks of a strategy in each of these two areas. The first subsection examines the investments needed to improve and expand distributed simulation capabilities. The second explores the kinds of management changes needed. These two areas should form the core of DoD's efforts in applying simulation technology to improve the development process, and represent the main focus of the discussion in this section. There are, in addition, a number of other acquisition reform initiatives—particularly "prototyping plus" and "dual use"—that can also benefit from simulation capabilities. We discuss these at the conclusion of this section.

A. ELEMENTS OF AN INVESTMENT STRATEGY

Realizing the full potential of simulation in the defense acquisition process will require large investments over many years. The purpose of this section is to summarize the areas where investments will be needed. We describe six main building blocks that should compose an investment strategy for simulation, i.e., simulation hardware and software; application tools; communication standards and protocols; behavioral models and data; VV&A; and education and training (Table IV-1) These building blocks form the general outline that can be fashioned into a fully developed strategy by identifying specific projects within each area and appropriately balancing resources across areas. The priorities within this strategy should reflect the current state of the art and ongoing development activities in each area, and allocate resources appropriately to achieve balance in progress across capabilities. Each area is discussed in turn.

Table IV-1. Investment Strategy Building Blocks

Investment Area	Main Developmental Funding Source
1. Hardware and Software Supporting Distributed Simulation Networks	Commercial
2. DoD Application Tools • Simulation Construction Software • Manned Combat Simulators • Semi-automated Forces • Weapon Production Process • Simulators	DoD
3. Cross-Functional Standards, Protocols, and Bridges	DoD, DOC, and Commercial
4. Underlying Behavioral Models, Data Bases, Data Capture Instrumentation, Data Reduction and Analysis Software	
• Combat	• DoD
• Engineering and Manufacturing	• DoD and Commercial
• Support	• DoD
• Cost and Schedule Mgmt.	• DoD and Commercial
5. Verification, Validation and Accreditation (VV&A):	
• Combat	• DoD
• Engineering and Manufacturing	• Commercial and DoD
• Support	• DoD
• Cost and Schedule Mgmt.	• DoD and Commercial
6. Education and Training	DoD and Commercial

1. Investment Strategy Building Blocks

The first building block comprises basic computer hardware and software, including networking capabilities. The highly competitive commercial technology markets are providing rapid increases in computer speed and capacity, graphics capabilities, and data network capacity. A recent Defense Science Board study of advanced distributed simulation concluded that these commercial developers would drive advances in these generic simulation technologies [DSB Sim 1993, Appendix A]. This area represents an important example of dual-use technology. The DoD should rely on these commercial developments and focus its efforts on adapting them as needed for defense applications. An even more activist approach would be to support basic research. For example, the DoD could support research on flat panel displays which will have significant civilian and defense applications. The DSB also prepared a table of technologies and the major sector which drives each technology. That table is given in Table IV-2.

Table IV-2. Key M&S Technologies and Source of Major Support[a]

Areas Driven by Commercial Market	Technologies Driven by DoD
Integrated Circuits Micro computer systems Local-area networks Fiber-optic communications Wide-area networks Computer image generators High performance computing Memory Mass storage Microprocessors High resolution video displays Data base management systems Software engineering tools	Manufacturing process simulators Engineering design modeling and simulation Manned simulators Stochastic wargaming simulators SAFOR (Semi-Automated Forces) Instrumented range systems Environmental models/data bases Human representation models Human ergonomics data bases Instrumented range systems DoD protocols and standards Multi-level security techniques Modeling and simulation construction tools

a. [DSB Sim 1993]

Even if the DoD does not support generic simulation technologies, there is a wide range of application tools specific to DoD's needs that need to be developed. These compose the second building block. Included are combat applications of generic technologies. The DoD needs to develop the manned simulators, combat environments, and automated forces needed for applying simulation to the combat environment. Investments will be needed in the engineering and manufacturing communities as well. These primarily relate to materials or manufacturing processes that are unique to military items, such as stealth manufacturing technologies. Most of the DoD investments in simulation technologies to date have concentrated in these types of application-specific tools.

The third building block includes the data standards and bridges needed to connect the simulation effort within the various functional communities. Many years of investment will be required before it will be possible to freely exchange data across functional boundaries, but if this vision is to be realized, the DoD must begin to take steps in that direction today. An important focus of this effort is extensive interaction with commercial developers to create the architectures and appropriate bridges needed within and between commercial and DoD-specialized families of simulation. The goal is for key personnel within each of the functional communities to exchange information via these interfaces with each of the other communities. Such information would include descriptions of the systems, associated environments, and scenarios and performance data such as the capabilities and limitations of the proposed designs within the stated environmental conditions and scenarios. These data should be available with variable resolution, fidelity, and aggregation as needed by personnel in each functional community.

Although there is a tendency to focus on the technical challenges of building the simulation networks themselves, the bedrock upon which a simulation network must be built is its performance models and data bases. These make up the fourth building block of a simulation investment strategy. The development of the underlying models, data, and analytical tools needed for the combat and support families of simulation must come from the DoD because these tend to be specialized. The models and data for engineering and manufacturing, and management tend to be dual use technologies, so DoD and commercial support is available. Extensive investments will be required over many years to build the needed library of models and data needed to fully realize the potential of simulation in defense acquisition. The need for such a library—along with a user guide to facilitate ready access for future developers—should be recognized as a key part of the overall investment strategy for simulation.

The fifth building block, verification, validation, and accreditation (VV&A), is one of the most sensitive issues in dealing with models and simulations. It cuts across all families of simulation and affects each of the functional communities. The credibility of any model or simulation rests on the adequacy of the models or their data bases to represent the real world. Each model must be verified to ensure that it performs as specified in the approved design. Verification turns out to be a matter of degree for most complex models, because it is impossible, in practice, to test these models over the entire range of variable values. In addition, it is often not feasible with the available resources to do a line by line check of the code. Proper processes need to be established and utilized by organizations to ensure a simulation can be verified.

Validation, on the other hand, must ensure that the model (and its data) predicts, within specified levels of confidence, the behavior of the real system being modeled. A model may be characterized as being valid in several ways [Davis 1992]. It may have descriptive, structural, or predictive validity. "Descriptive validity" means that the model is able to explain phenomena or organize information meaningfully in one way or another. A model has "structural validity" if it has the appropriate entities, attributes, and processes so that it corresponds well with the real world. "Predictive validity" means that a model can predict desired features of system behavior to within some known level of accuracy and precision. Predictive validity relates to the issue of extrapolation error raised earlier. To enhance the validation of a model, people from each functional community and with diverse experiences may need to lend their observations and concerns. This is particularly needed when a system's behavior is to be estimated in a large set of environments and scenarios.

Finally each simulation must be certified or accredited according to uniform criteria that clearly state the capabilities and limitations of the simulation, the interface requirements for linking the simulation with other simulations, the environment within which the system simulation is to operate, and the scenarios describing how the system being modeled is to be used. In effect, accreditation is an official determination that a simulation is acceptable and for which specific purposes or classes of applications.

There is another issue which is related to VV&A—the repeatability of results. Especially in the use of manned distributed simulations, the expense and complexity of such simulations may not permit sufficient data to be taken with enough diverse personnel to gain sufficient statistically significant information. Reconnections of the distributed simulations may also be difficult and thus complete repeatability may not be possible.

The sixth investment building block is the education and training of acquisition personnel in the application of modeling and simulation. The SIMNET activities have greatly facilitated the education and training of both helicopter and tank personnel. Extensions to other functional communities have not yet been given priority. In time, these tools will become standard offerings in the training of personnel in all functional communities and other phases of acquisition. Currently there is little organized effort directed in this critical area.

2. Funding

The recent Defense Science Board report on modeling and simulation identifies several major programs currently funding investments in simulation [DSB Sim 1993]. ARPA and the Defense Modeling and Simulation Office (DMSO) together provide about $110 million for simulation-related research. In addition, each of the Services is funding specific application projects. Currently, the DMSO, which supports the Executive Council for Modeling and Simulations (EXCIMS), and the Steering Group, which is helping the Science and Technology Thrust 6, "Synthetic Environments," are the two main entities reviewing ongoing programs. Both will influence plans to set DoD priorities for future simulation investments. Such a process should help provide the needed balance across the areas discussed.

Other important funding sources for creating the needed simulation building blocks are ongoing acquisition programs and demonstration programs of selected technology applications and those of simulation technologies and management practices. Numerous ongoing applications of functional simulation were described earlier, but in addition there are a number of demonstration projects proposed or underway.

The current and proposed program of the Science and Technology Thrust 7, Technology for Affordability, includes a series of demonstrations of manufacturing processes for major system components, mostly involving electronics. This approach has been extended to experiment with complete missile systems, and could be extended to major subsystems of ships or aircraft, e.g., an aircraft wing or a section of a ship hull. The recent Defense Science Board summer study on manufacturing has also proposed a number of Advanced Technology Demonstration (ATD) programs for testing new development approaches. These include the Army's Composite Armored Vehicle, the Light Contingency Vehicle, and the Advanced Field Artillery System. Two other proposals include the Multirole Fighter Engine and the Integrated, High Performance Turbine Engine Technology (IHPTET) [DSB Man 1993]. Whatever programs are selected for such demonstrations, the demonstrations should be designed to help create the needed building blocks that will in turn contribute to a cumulative base of simulation capabilities.

This discussion of simulation building blocks provides a starting point for creating an investment strategy. The vision of simulation as a tool supporting a functionally integrated acquisition process provides a guiding principle for targeting these investments. But this vision is only a point of departure: a fully developed strategy for simulation will require an extensive effort from DoD leadership, with help in the adoption of the management practices and the support of each of the functional communities to address the technical issues. The creation of such a strategy properly belongs in the hands of the communities that develop and use simulation. A model for such a process is the DoD's existing Science and Technology Thrust and the EXCIMS processes. These processes bring together working-level officials to create a unified view and direction for science and technology programs. A similar effort involving working-level people within the broader acquisition community, i.e., government and industry—which could be formed under the sponsorship of the DMSO as it has sponsored the Distributed Interactive Simulation (DIS) efforts—would form an appropriate mechanism for creating a simulation investment strategy.

DMSO has initiated a task force which seeks to:

- Develop and recommend actions to advance the effectiveness and efficiency of the application of modeling and simulation throughout the acquisition process.
- Identify and recommend improvements to the acquisition process which could result from the integrated use of modeling and simulation.

To help DMSO and this task force, an industry group has been formed. It too will develop its recommendations for industry and DoD activities.

B. MANAGEMENT INITIATIVES FOR FUNCTIONAL INTEGRATION

Management initiatives form the second area of the DoD's agenda which is needed to create a functionally integrated acquisition process. This section identifies some of the issues involved. We begin by summarizing the challenges that have been faced in the commercial world and then illustrating the nature of the problems that need to be addressed in changing the acquisition process within the DoD. We then focus on four key principles that will have to be adopted within the DoD in order to achieve full functional integration in the acquisition process. We conclude that most of the needed changes can be made within the existing formal acquisition process, but there are a few areas where legal or regulatory changes are needed. These are discussed at the conclusion of this section.

1. Lessons from Commercial Experience

We described earlier how U.S. firms have improved productivity by incorporating new management practices. This section raises some issues regarding the implementation of these new approaches. The major observation that can be drawn from the commercial experience is that many of the firms that have made the greatest improvements are those that were driven to the brink of bankruptcy by foreign competitors or other reasons. They were forced to innovate or die. This pattern is evident among some of today's most progressive commercial firms.

Xerox is one well-known example [Kearns 1992]. During the late 1970s and early 1980s, Xerox's share of the global market shrank from 82 to 41 percent. Japanese makers were selling copiers for less than Xerox's costs. Xerox realized it would have to revitalize its operations. By 1985 it had cut its product development cycle by 50 percent and reduced product costs by 50 percent. Xerox has begun to regain market share. Similar stories can be told about some U.S. auto makers. The Ford Taurus project discussed earlier was undertaken in the early 1980s when the survival of the company was in doubt.

Numerous other commercial examples fit this pattern as well. John Deere, like many other American firms, was pressed into radical corporate restructuring by a combination of stiff foreign competition, labor discontent, and a slump in demand for capital investment. Deere's inability to compete was due in large measure to the overly complex design and production system that had evolved when it was a predominant supplier of agricultural equipment. To become more competitive, Deere initiated cultural changes throughout the company. Among other steps, Deere integrated customer feedback in the development process and instituted computer-based support activities. The results were remarkable. Product quality increased, requiring 66% fewer inspectors with increased customer satisfaction. Development costs fell 30%, development time fell 60%, and developmental builds were cut from four to one. Parts inventories were cut by 65%. Deere continues to address other approaches to become even more competitive.

Many other firms that are cited as success stories today were forced to adapt under extreme duress. They include such leading manufacturers as Caterpillar Tractor and Harley Davidson. In every case, competition forced these companies to adapt to survive. Indeed, their dire straits made changes easier because management and workers alike recognized that the future of the company required dramatic increases in productivity. This pattern suggests how hard it is to realign corporate power relationships as needed to adopt new practices within the concepts, engineering, manufacturing, and other functional communities. Traditional stovepipe hierarchical structures must be forced to work as teams instead of competing power centers.

This commercial experience underscores the challenges DoD will face in implementing these new management practices. New technologies such as distributed simulation can assist, but in the end the fundamental challenge is to create a development process within the DoD acquisition system that is compatible with four key principles which we have identified as being key within the new management practices. The four key principles are:

- Strong leadership
- Functionally integrated development team
- Clear communication and expectations
- Simultaneous development

The question is, how can these principles be applied in the absence of an organization-threatening crisis, such as the ones that forced commercial firms to adapt? The loss of the Soviet threat would seem to undermine the pressures for change. On the other hand, budget pressures, combined with the opportunities created by the new distributed simulation technologies discussed here, and the demonstrated success of U.S. commercial firms in adopting these new principles, may be an adequate catalyst for change. At a minimum, such changes will require leadership from the Services, Joint Staff, and the Office of the Secretary of Defense.

2. Functional Integration Within DoD Programs

What will be required to implement these four principles of the new management practices in the internal DoD and its supporting contractor programs? Several characteristics of the approaches suggest the kind of process needed. First, however, DoD's experience leads us to add a fifth principle: *effective risk management*. The implementation of each of these five principles raises management issues that will need to be addressed as an appropriate acquisition process is designed (Table V-2).

Strong Leadership. The first question is, how to manage the cross-functional team participation? Successful commercial developers have adopted a teaming approach to create the program concept. This approach involves a strong leader plus key representatives from each of the major functional communities which will be involved in fielding, operating, and supporting the system. The challenge is to apply this approach within the DoD; its breadth must be expanded beyond the commercial experience to include all six of the DoD's acquisition functional communities.

Table IV-3. Adapting the Key Management Practices to Defense Acquisition Programs

Key Principles of the New Management Practices	Issue in DoD Applications	Possible Applications
Strong leadership	How to incorporate checks and balances • Independent test • Independent cost • Congressional oversight	Government-wide participation • Participate with support form strong leaders from all functional communities Government-industry teaming
Functionally integrated development team	How to overcome the traditional practice of stovepipe development	Create functionally integrated teams for ATDs and ACTDs Create functionally integrated teams for concept exploration and demonstration/validation phases of acquisition
Clear communication and expectations	How to clarify project expectations How to efficiently perform oversight functions	Document program performance metrics Clarify expectations by basing programs on demonstrated technologies and processes
Simultaneous development	How to define/select manufacturing processes during the design development How to address testing and support options during the design process How to modify performance requirements to save cost/schedule	Include production options within the engineering design phase Have testing and support personnel closely involved in the design process Have the user community prepare option when major cost/schedule obstacles arise
Effective risk management	How to overcome the traditional problem of entering engineering and manufacturing development with excessive risk	Set clear risk thresholds to ensure design convergence before entering engineering and manufacturing development Use ATDs and ACTDs to explore all dimensions of program risk

Similar integrated approaches have been suggested before but found to be almost impossible to fully implement because the governmental procurement system, with its inherent checks and balances, has given rise to a layered, bureaucratic process for overseeing programs. "Black programs" have sometimes been an exception because such programs typically exclude involvement by all but a small team of cognizant officials outside of the program itself. They provide one model for DoD teaming, but they are not the final answer because there is concern that their checks and balances are too weak. A new hybrid program structure is needed that can implement the best of these principles without unduly sacrificing needed checks and balances.

Implementing this new principle also creates difficult policy issues: how can integrated engineering teams be established within the government acquisition environment, where traditionally these functional communities have operated at arm's length? Is it possible to create the kind of teaming arrangements needed to fully implement these techniques and still retain the independence of oversight functions such as independent testing, costing, and auditing? In the corporate world, checks and balances are built in when establishing the development team through an appropriate set of management incentives. Whether this approach can ever be fully implemented in the government acquisition environment remains to be determined. A key question is whether appropriate incentive mechanisms can be designed and implemented to explore ways to improve the organizations [Rupp 1993, pp. 275-330]. The identification of these mechanisms should be at the top of DoD's agenda for many reasons and not just for incorporating simulation in the acquisition process.

Functionally Integrated Team Development. The second question is, how to organize a team's work to ensure that it follows an integrated development process rather than the traditional sequential process? The sequential approach is implicitly—if not explicitly—embodied in the DoD milestone process, which traditionally has focused on first defining performance requirements; second, validating the feasibility of performance design; and third, developing the manufacturing and support infrastructure. Integrated development implies that instead of this sequential approach, each of these considerations should be given balanced weight at each point in the development cycle. To do this, the development process needs to be restructured to make it clear that every function receives appropriate consideration at each step. As an initial step, each of the DoD's Advanced Technology Demonstration (ATD) and Advanced Concept Technology Demonstration (ACTD) programs should be designed to achieve a balanced set of objectives covering each of the six functional areas. This also means that each of the six functional communities must be considered from the very beginning of program definition. From that base, representative new system programs should incorporate such balance.

Clear Communication and Expectations. The third question is, what changes are needed so that development teams can establish clear lines of communication with each of the functional communities including senior DoD managers, oversight officials, and the budgeting processes? Two elements must be addressed. The first key for successful communication is for the development team to clearly define standards of success for their program. In an integrated development program, team members representing oversight functions should join with the other functional communities in defining program performance metrics. For example, both program engineers and testers will understand what is required to successfully complete developmental and operational tests. Such metrics would serve as a basis for communicating up and down the management chain, as well as across functional boundaries. Nothing is more corrosive to relationships between the development team and oversight officials than a disappointment resulting from unrealistic program expectations. Programs based on established technologies incorporated into a weapon concept by a cross-functional team should be more realistic than many programs traditionally have been, and this added realism fosters improved communication.

Simultaneous Development. The fourth question is, how can each of the many different functional communities develop its contributions to the design simultaneously? Often the best design is very dependent upon which particular manufacturing plants will be producing the various parts of the system and supplying the logistics needs; the particular location and way the system is going to be tested (both development and operational); and the concept through which it will be supported and repaired. Each production plant has differing capabilities and significant cost savings can occur if the design is modified to accommodate the capabilities of a specified manufacturing site. Since testing is an integral part of the development process, key data must be readily obtainable throughout the development cycle in order to assess the performance of the system. Since each test site has differing capabilities, the design can be varied to ensure maximum compatibility with the selected tests sites. Life cycle costs are driven by the operational and support costs. Options for usage, not just operational performance, need to be reviewed extensively during the design phase. Logistics and support concept options also vary both from a legacy aspect as well as possible other new systems; both need to be an integral part of the design activities.

To help ensure that all of these factors are properly included within a design, all of these aspects should be considered nearly simultaneously instead of sequentially. This would avoid costly, long, and drawn out iterations of the design. The goal is many iterations, in a short period of time, of both basic design concepts and the detailed subsystems. By keeping a close watch on the overall performance and other associated goals, more detailed design aspects can be developed collectively by key personnel from all of the functional communities. Consequently, each community will need to address functional and interconnection roles during the design development process.

Risk Management. Finally, the fifth question is, how to structure programs to ensure effective risk management? Successful commercial developers have adopted the TQM adage of "do it right the first time" in their development programs. An important corollary of this approach is the need to reach design convergence before beginning detailed engineering and manufacturing development. The data on DoD program experience presented earlier suggests that effective risk management could substantially reduce development costs by reducing the changes and rework needed in full-scale development.

The DoD is already placing greater emphasis on risk management in the acquisition process. In particular, the feasibility of new technologies is now supposed to be demonstrated through ATD or ACDT programs prior to their incorporation in an acquisition program. The recent DoD acquisition strategy contains, as one element, an increased emphasis on the use of ATDs. ATDs are to be used

> . . . to conduct more rigorous 'up-front' technology developments so that the acquisition cycle can be made less risky . . . These . . . will range from demonstrating the military utility of new technological concepts in a laboratory environment to integrating and assessing technology in as realistic environment as possible. [DoD 1992, p. I-16]

But discipline and careful attention are needed to make this approach work. Simulation technologies can play a major role in this because, as we have seen, these technologies, used in combination with traditional development processes (engineering and manufacturing) and their development tools, can provide a cost-effective way for the DoD to identify risks early and thus reduce them in the initial development phases.

The five principles of these new management practices—strong leadership, functionally integrated team development, clear communications and expectations, simultaneous development, and effective risk management—provide the basic guidance needed for improving defense development programs. As we have shown, some of these principles can be implemented within the DoD's existing formal acquisition process. In particular, there are no formal barriers to improving communications and risk management. Although the process does not prevent simultaneous development, it strongly discourages the creation of the fully integrated development teams needed to implement simultaneous development. The reasons are the legal and cultural barriers to teaming involving all six functional communities. Earlier, we posed the question, is it possible to create the kind of teaming arrangements needed to fully implement these techniques and still retain the independence of oversight functions such as independent testing, costing, and auditing? The main challenge facing the DoD is to provide a convincing affirmative answer to this question.

C. SIMULATION AND ACQUISITION REFORM

We believe distributed simulation's ultimate contribution will be in supporting functional integration in weapon development programs. Nevertheless simulation capabilities also contribute to other acquisition process reform goals and recent acquisition process reform proposals. Two of the main reform proposals under consideration are "prototyping plus" and "dual use." Prototyping plus provides a strategy for maintaining military technology leadership despite shrinking defense budgets, by spending a greater share of modernization resources on prototypes and limited production runs. This strategy focuses on demonstrating and testing leading-edge technologies, with the idea that large numbers could be fielded if and when the need arises. It is consistent with many of the recent attempts to define a more flexible acquisition process. These include *virtual swords* [Gold 1990]; *flexible acquisition* [Richan 1990, pp. 15-17]; *rollover-plus* [Aspin 1992]; *prototyping-plus* [OTA 1992, pp. 12-13, 51-75]; and *dual-track prototyping* [OTA 1989, pp. 11-13].

The dual use acquisition strategy is aimed at reducing the DoD reliance on defense-specialized suppliers. This would include generation of the needed new and military-specific designs for parts and components by defense-specialized suppliers. This strategy would also allow the DoD to tap the nation's (and perhaps the world's) broad commercial base, reducing acquisition costs and increasing the potential pool of suppliers. We will briefly outline the implications of these strategies for the defense acquisition process, and describe the role that simulation could play in such a process.

1. An Acquisition Process for Flexibility and Dual Use

A milestone structure that incorporates the flexibility entailed by the prototyping plus strategy requires breaking the traditional acquisition "pipeline" by de-coupling the front end of the process from the development and production steps (Figure IV-1). The front

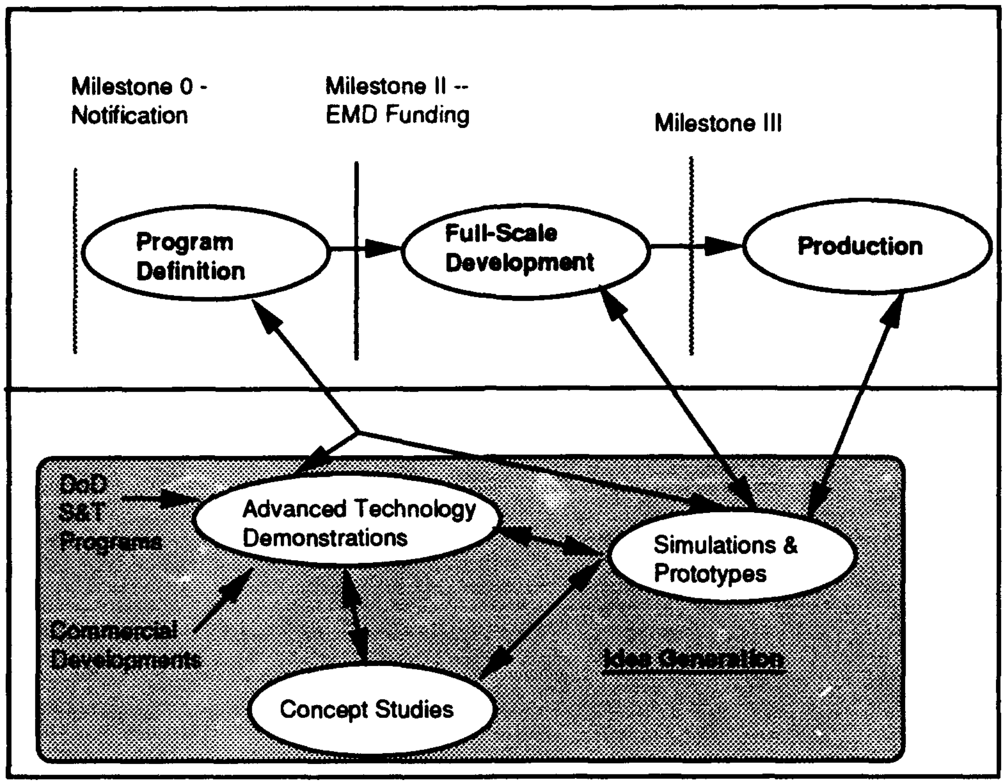

Figure IV-1. Acquisition Reform and the Milestone Process

end, "idea generation" process must allow new ideas and proposals to churn indefinitely without the necessary detail planning that makes up a full new program start. The remaining steps in the acquisition "pipeline" should be restructured to (1) incorporate the five principles, and (2) shift the new program start decision to the beginning of detailed engineering and manufacturing development. This framework would provide flexibility, both in the timing of programs and the magnitude of buys. The timing of new programs is controlled through the flexibility in the idea generation process. New technologies and manufacturing processes in a warfare area can be created, prototyped, and simulated indefinitely without a commitment to undertake production. The size of buys can be managed at the same time decisions are made on the production concept, operational needs, and support capabilities.

Each of the steps in this functionally integrated system acquisition process is discussed in turn.

The first step is *idea generation*. The underlying principle of "prototyping plus" is that the acquisition system should be structured so that technologies can be developed without necessarily leading to a new weapon program start. Hence, the idea generation process must be de-coupled from the traditional acquisition "pipeline." Under the pipeline approach, technologies were only developed to meet a requirement for fielding a new system. Development activities were thus coupled with the plan to field the weapon, and scheduled to meet the associated system program milestone requirements. In a de-coupled framework, technologies would be managed by warfare area, and would be explored through an ongoing, level-of-effort research and development program coupled to the idea generation process, without necessarily being linked to a requirement to field a specific weapon.

At the heart of the idea generation process are ATD and ACTD programs. ATDs can be designed to serve a wide range of purposes. They may focus on a component, such as a weapon sensor; or a subsystem, such as a ship propulsion system; or even a fully integrated system, such as an armored vehicle or an aircraft. They may also demonstrate applications for a basic material or resource. In addition they could demonstrate a production process, a test capability or method, or focus on a logistics issue. ATDs, when combined into ACTDs, could produce a real prototype, or where simulation technology is sufficiently advanced, they could rely on a "virtual prototype." In parallel with these ACTDs, concept studies could examine the military application and utility of the demonstrated systems in a warfare area.

A typical ATD program may, for example, demonstrate the feasibility of advanced sensors. Subsystem prototypes coupled with engineering and manufacturing simulations could be used for examining the producibility of the new design. Parallel combat simulations might consider the utility of this sensor in performing military tasks—for example, finding high-value mobile targets in a WAR BREAKER type scenario. Based on these analyses, one of three choices could be made:

- The ATD could be allowed to lapse, having found the technology is not presently useful.
- A follow-on ATD could be commissioned, in order to start a new cycle of experimentation and simulation.
- A decision could be made to incorporate the technology in a new ACTD which would demonstrate a weapon concept or a weapon upgrade.

The idea generation process is intended to provide a continuous cycle of experimentation and improvements in each of the DoD's warfare areas. Because ATDs form the foundation for next generation programs, it is essential that a balanced program of ATDs be maintained. The DoD is adopting a strategic management framework for Science and Technology (S&T) Thrusts that provides the needed perspective to create a balanced, diverse program of ATDs [DoD 1992].

ATDs should also play a central role in supporting the DoD's dual use strategy. The DoD regulations have long stipulated a preference for off-the-shelf parts or components whenever possible [DSB Man 1993].[1] Thus Figure IV-1 shows that ATDs might incorporate commercial as well as defense-specialized technology. Despite these regulations, designers have strong incentives to maximize the performance of weapon systems, and very little incentive to incorporate off-the-shelf parts or components into their systems. If the DoD is serious about increasing the use of commercial components, a stronger set of incentives for developers will have to be created. The DoD can create the needed incentives by commissioning ATD projects with the express purpose of adapting commercial technologies to military uses. For example, a series of ATDs could examine how DoD navigation needs might be met with off-the-shelf global positioning unit technology.

ATDs can also support dual use strategies through their focus on manufacturing processes. Even when products are specialized for defense use, they may still be producible with standard, commercially available production equipment. For example, many components of the M1 tank are made in commercial job shops. Indeed, most of the machines used for making the M1 are found in large numbers in factories throughout the United States. The effort to broaden the supplier base should not be limited to requiring the use of off-the-shelf parts and components where possible; it should also include designing parts and components to make use of commercially available production tools. Small investments in design could substantially increase the range of producers capable of supplying parts and components for the next generation of weapons. The increased use of CAD/CAM systems and flexible manufacturing will increase the feasibility of this approach in coming years. It is recognized that procurement regulation reforms may also be needed for the dual-use concept to be effectively implemented.

The second step in the development process is *program definition*. In the envisioned framework, a functionally integrated development team would be established when the

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[1] The DoD's acquisition regulations reflect the preference for commercial products. DoD regulations provide a priority list of options to the actual development of a new system that must be considered prior to starting a new program. Heading the list are existing US. systems, followed by allied nation or commercial systems. The regulations also require the maximum practical use of commercial items. But such a provision is very difficult to enforce because a case can always be made that a custom-made component can do a job somewhat better. Thus, the provision may generate a new paperwork requirement for waivers but may have little real effect on development practices.

decision is made to begin a new program. Milestone 0 is retained in this framework, not as a hurdle, but rather as a notification requirement, informing all DoD communities of an organization's intention to propose a new program. The functionally integrated team would include, as integral members, people from all functional communities including independent testing, costing, and audit organizations. The intention is to eliminate the traditional adversarial relationship by creating a team working together to achieve common objectives. These individuals would help the team craft program performance metrics that include a wide range of success criteria in each community. The team would establish the basis for subsequent communication up and down the management chain and across the functional communities.

The dual use strategy should be carried into the program definition and subsequent phases. During these phases, the design process can be used to incorporate dual use technologies in two ways, just as was described for ATDs earlier: first, by inducing designers to use commercially available parts and components; and second, by designing defense-specialized components to be manufactured on commercially available manufacturing equipment. These tactics, although not universally accepted by some commercial firms, would substantially reduce the technological barriers to the integration of the defense and civilian production base.

The de-coupling of the traditional acquisition pipeline means that the major program start decision would be made later in the process than has traditionally been the case. Milestone II thus becomes the main program decision point. At this time a detailed program proposal would be reviewed and approved by the political leadership.[2] The program proposal would include much of the same information prepared for a Milestone II review today. This would include such items as a COEA (which may rely heavily on distributed simulation); a test plan with success criteria; a cost, schedule, and risk management plan; and a life-cycle support plan. The Services and OSD would form a "staffing team" to review these documents, and to raise questions when the program is presented to the Defense Acquisition Board.

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[2] In the theory of concurrent engineering, this decision should be agreed upon by all responsible corporate officials. In government procurement this would imply by analogy that milestone approval should be given by the sponsoring Service or Agency, the Secretary of Defense, the President, and the Congress. The approval process among these people represents an important issue that must be addressed in applying concurrent engineering within the acquisition process, but it is beyond the scope of this study. The reader is referred to [DSB Man 1993].

An important component of the Milestone II decision point is an increased emphasis on effective risk management. Decision criteria for Milestone II should therefore include a risk management threshold. This threshold can be set relatively high because it should be possible to achieve design convergence prior to the third step, full-scale development, given that program proposals are based on ATD and ACTD building blocks. Of course, there will always be some problems that emerge when a system enters development, but this approach will reduce the problems that have traditionally been encountered when a program enters engineering and manufacturing development. Simulation used throughout the process will provide early learning to reduce risk and thus reduce cost.

Since Milestone II approval for entering full scale development, in practice, entails a large commitment of funding, it should only be done when some level of production is anticipated. The integrated development team would have developed the basics of the manufacturing processes concurrently with the product design prior to the Milestone II decision. The goal of the number of units, or at least the range of units, to be produced must have been previously established so that the scale of the production system would have been known. There is, of course, complete flexibility in deciding on the planned scale of production. The level of production agreed upon at Milestone II may be very limited for some programs, where the intent is only to develop and try out a new weapon technology. Or a decision may be made to create a small-scale production system designed to be expanded if necessary at some future time. In other cases, the intention may be to build enough to fully modernize the force. The DoD process thus could accommodate a flexible approach to acquisition.

This proposed process would significantly cut the time required to develop a weapon. There are two main reasons for this. First, much of the time that is often occupied with the churning of new ideas and sorting out preferred technological options at the outset of traditional acquisition programs would be spent within the idea generation process. Secondly, new programs would have a firmer base of technological options to build upon since they would be using the ATD and ACTD prototypes and simulations. As a result, the development of the program concept should proceed relatively quickly once a decision to define a new program is made. Although idea generation can proceed at measured pace in this process, a more effective development process, combined with the improved management of risk, should significantly shorten the time required for development and reduce cost.

The forth acquisition step is *production.* The program proposal reviewed at Milestone II would include criteria for Milestone III approval to enter production. Key in this concept is the inclusion, within the design iteration process, of the particular production processes to be used in the manufacture of the system.[3] In those cases where a program proceeds more or less according to plan, approval would thus be *pro forma*. When programs run into problems, Milestone III would be a problem-solving session in which program alternatives would be weighed in view of the development problems incurred. Documentation and staffing for Milestone III would focus on the problems, and thus would vary to fit the circumstances.

2. The Roles of Simulation

Distributed simulation provides a number of capabilities that support this flexible acquisition process (Table IV-3). In the idea generation step, simulation serves to complement and assess ATDs and ACTDs. As technology is demonstrated, simulation capabilities can explore possible applications and can combine various technologies to explore system of system applications. Many of the examples discussed earlier show how the DoD is already using simulation technologies to evaluate technologies at this early phase of their development.

As programs proceed into program definition and development, distributed simulation will act as a tool supporting functionally integrated development. The simulation capabilities of visualization, performance modeling, common data, and user interaction apply in these phases in the ways discussed earlier. One additional application that was not emphasized earlier is the use of simulation in communicating program parameters to oversight authorities at the Milestone II decision point. This could make a significant contribution to the understanding of the program and the effective management of risk.

Acquisition reform and simulation technology improvements will interact synergistically to improve the acquisition process. The full use of simulation directly supports functionally integrated development which should be a key feature of any acquisition reform. Yet acquisition reforms will set in motion the need to more enhanced understanding among all parties involved within acquisition and such needs will spur the incorporation of simulation to aid in that understanding. We find that although some of the principles of these management practices can be implemented within the current formal acquisition system, some changes and/or reforms are needed to create fully integrated development teams.

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[3] Not all production facilities have the same capabilities. The "final" design should not be derived until the actual production facility has been selected. The processes unique to that facility need to be included within the design and those capabilities discussed within the Milestone II review.

Table IV-4. The Role of Simulation in a Flexible Acquisition Process

Program Step	Roles of Simulation
Idea Generation	• A virtual prototype to substitute for real prototypes in some ATDs • A combat worth assessment tool which can incorporate human factors and tactical innovations • A tool for evaluating system-of-systems ideas • An engineering and manufacturing analytical tool to complement real experimentation • Dual use: a communication tool for identifying commercially available parts, components, and processes
Program Definition	• A communications tool for functionally integrated teams • Analytical tools for use by each of the functional communities • Program visualization for Milestone II reviewers, committees, and DAB members • Dual use: a communication tool for identifying commercially available parts, components, and processes
Full Scale Development	• Provides early learning for risk reduction and cost avoidance • A communications tool for functionally integrated teams • Analytical tools for use by each of the functional communities • Dual use: a communication tool for identifying commercially available parts, components, and processes
Production	• Tool for assessing alternative manufacture processes when needs change • Production process simulations to optimize manufacture of multiple products on same lines

V. FINDINGS AND CONCLUSIONS

The commercial experience cited at the outset of this paper provides benchmarks for estimating the gains possible in the DoD's development programs. It also pinpoints two fundamental changes needed to apply the new management principles to defense programs. First is to break down the traditional development "stovepipes" or barriers between the functional communities. Development *teams* should integrate across the functional communities of requirements and concept development, engineering design and manufacturing, test and evaluation, logistics and support, force planning and budgeting, and program management. Second is to manage risk more effectively. Now that the Cold War is over, programs should not start full-scale development before major technological, operational, and support problems are resolved.

In addition to these management improvements, the leading commercial firms are also aggressively exploiting simulation-related development and manufacturing technologies. The role of simulation is suggested by the four capabilities it offers. The first is *visualization*. Visualization may be static or dynamic, but it permits all who view an item to far better understand its design and function, allowing problems to be surfaced before hardware is built. The second capability is broad-based *performance modeling*. This could include simulating physical performance such as mechanical stress or a weapon in combat. This gives users and developers a more complete understanding of how a component or system would work in the real world. The third capability is a *common information base*. It gives all team members up-to-date data on designs, and facilitates rapid iterations in design and associated processes as problems are surfaced. Finally, the fourth capability is *user interaction*. This could range from manufacturers marking up drawings from locations remote from the designers, to test pilots participating in simulated air-to-air combat, to the interaction between logistics planners and system designers.

Simulation technologies providing these capabilities provide a powerful tool for implementing a functionally integrated acquisition process. Visualization, performance modeling, and user interaction assist communication both within and across functions, thus breaking down stovepipes. Performance modeling, common information, and user interaction all assist analysis and should significantly improve the management of risk.

The degree to which simulation can actually provide these capabilities—both today and in the future—depends on the power and acceptance of the available simulation tools. Our examples show there are valuable applications of simulation within each of the DoD's functional communities. But as yet, there is little success in integrating simulation across functional boundaries. Currently, most simulations fall into four separate families of simulation: combat, physical, availability and support, and cost and schedule. While combat simulation may get the most attention, less glamorous but cost-effective applications have been made in each of the functional communities. We find, however, that most existing simulation tools have been tailored to the needs of the communities that use them, so they have not been designed to communicate across functions. Consequently, the best available simulation practices are not uniformly applied across programs.

When simulation capabilities are fully matured, distributed simulations will electronically connect together the system design representations and the analysis tools of all acquisition disciplines and functions. They will involve the many different internal DoD acquisition-related functions and organizations and the associated defense industries. They will provide a more effective way to participate in the iteration and refinement of system designs. These iterations will take place long before the first piece of production metal is cut or before the first line of operational computer code is written, and will be used in the acquisition of both new and re-designed systems. Key personnel within each of those functional communities will be able to:

- More easily assess the system's cost effectiveness within proposed environments and scenarios from the perspective of their own discipline; through this tool they will able to extend the utilization of their own discipline's analysis tools. Through the use of simulation, they will be immersed in the system operation as it is viewed from within their own functional discipline. This will provide a greater understanding of the system's operation and effectiveness within other disciplines. These key personnel will be able to directly transfer the designs, environments, and scenarios into their own functional models and simulations electronically, and thus avoid many or all of the data input errors. They can conduct analysis on those designs, environments, and scenarios using their own detailed and validated, verified, and accredited models and simulations.
- Communicate potential problems in the designs, environments, and/or scenarios, and offer suggestions or other options. Team members will be able to express

their concerns and suggestions into a common electronic medium. Their comments will be sent, along with the representations, directly to the designers and responsible system integrators.

- Accept and collectively validate an optimized system design and the associated environments and scenarios. As integrated team members, these key personnel will be able to consider all concerns and suggestions raised by the various disciplines and help reach an understanding of and an overall rationale for the designs, environments, and scenarios. By "signing off" on each major iteration of the design and the associated environments and scenarios, they will be giving their approval to the design.

Distributed simulations, when applied in a functionally integrated system acquisition process, will capitalize on expanding information technology, complement the numerous new acquisition enhancement approaches, and will incorporate the existing extensive modeling and simulation capabilities within each of the functional communities. Since most of the key personnel within those communities are already geographically dispersed and yet need to be actively involved in each phase or iteration of the acquisition process, distributed simulation offers a very effective means to collect the ideas of those key people. This concept also permits:

- Considering the latest technologies for incorporation within potential new systems or re-designed systems.
- Anticipating, as best as possible, major costly errors so they can be avoided.
- Developing the best designs that can be ready for production when deemed appropriate.

It also supports evaluating the designs in diverse environments, in differing scenarios, and with optional mixes of systems with which this system may need to operate.

We have described six main building blocks that should compose an investment strategy for simulation, i.e., simulation hardware and software; application tools; communication standards and protocols; behavioral models and data; verification, validation and accreditation; and education and training. These building blocks form a general outline that can be fashioned into a fully developed strategy by identifying specific projects within each area and appropriately balancing resources across areas. The priorities within this strategy should reflect the current state of the art and ongoing development activities in each block, and allocate resources appropriately to achieve balance in progress across capabilities. In doing this, the DoD should take advantage of ongoing commercial simulation technologies because the commercial sector is leading in the development of engineering simulation and manufacturing tools, as well as in the development of simulation and networking hardware. It should also be recognized that many of the functional communities will continue to develop their own capabilities to meet their own requirements.

The DoD's acquisition community can most effectively emphasize initiatives and investments in those areas that will not otherwise be supported. These initiatives include the following:

a. Design an acquisition simulation architecture that encompasses all of the acquisition communities and families of simulations and provides bridges between them. This architecture should:
    1. Describe interfaces between the simulations used within each type of simulation, simulation family, and functional community.
    2. Define subarchitecture options which may be most useful within each community, yet be interconnectable by means of an overarching architecture and thereby to those within the other communities.
    3. Develop variable resolution simulation capabilities within simulation families as required by each functional community.

b. Create a user guide for simulation in acquisition that describes best practice applications of modeling and simulation within and across functional communities, along with lessons learned. This guide should:
    1. Provide an overview text for program managers—incorporate this within the Defense Systems Management College curriculum.
    2. Inform all personnel within the acquisition discipline of the benefits, limitations, and approved use of distributed simulation.

c. Develop new cost and schedule simulation tools that show how advances in management practices and developing technologies can be incorporated in structuring new programs. These tools would:
    1. Expand the use of Activity-Based Costing (ABC) within programs.
    2. Incorporate Material Resource Planning data directly into cost models.

d. Develop the means to directly interconnect the cost analysis parameters with the detail design, manufacturing processes, logistics concepts, testing and evaluation options, and other key cost driving functional activities.

e. Develop an appropriate distributed simulation security environment so that classified, proprietary, and personnel sensitive data can be readily exchanged among authorized simulations and users.

f. Invest in the infrastructure needed to apply simulation in acquisition programs. Investments should be designed to:

1. Build accessible data bases that capture prior experience and help prevent reoccurrence of mistakes.
   - Develop ways to obtain field training data to help acquisition programs better understand the capabilities of soldiers in the field.
   - Record lessons learned from previous acquisition programs.
   - Catalog contractor-delivered concept designs and engineering data so follow-on programs do not need to "start-over."
2. Improve simulation development tools, including tools for VV&A, variable fidelity, and aggregation/deaggregation.
   - Develop a capability maturity model for evaluating organizations that develop and use models and simulations. This would be similar to capability models that are used to help assess the capabilities of software developers.
   - Develop measures of fidelity to be used scoping VV&A activities.
   - Develop logical and mathematical bases for proper aggregation and deaggregation of enities within and among simulations.
3. Establish widely acceptable standards by which the models and simulations can be developed, including data exchange standards to facilitate exchanges within and among the functional communities.

In addition to these initiatives that mostly center on activities of the acquisition functional communities, we also feel that appropriate incentives need to be defined for organizations both within and supporting the DoD to help encourage them to adopt the key management principles which commercial industries have found necessary to attain an functionally integrated acquisition/development process. These principles are:

- Selecting strong program development leadership.
- Using functionally integrated development teams.
- Establishing clear communications and expectations.
- Conducting simultaneous development.
- Implementing effective risk management.

This discussion of simulation building blocks provides a starting point for creating an investment strategy. The vision of simulation as a tool supporting a functionally integrated system acquisition process provides a guiding principle for targeting these investments. But this vision is only a point of departure—a fully developed strategy for simulation will require an extensive effort from DoD leadership with help in the adoption of the management practices and the support of each of the functional communities to address the technical issues. The creation of such a strategy properly belongs in the hands of the communities that develop and use simulation.

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LIST OF ACRONYMS

ABC	Activity-Based Costing
ACTD	Advanced Concept Technology Demonstration
ADATS	Air Defense Anti-Tank System
AMRAAM	Advanced Medium Range Air-to-Air Missile
ARPA	Advanced Research Projects Agency
ATACMS	Army Tactical Missile System
ATD	Advanced Technology Demonstration
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
CALS	Continuous Acquisition and Life-cycle Support (previously known as Computer-Aided Acquisition and Logistics Support)
CAM	Computer-Aided Manufacturing
CAM-I	Computer-Aided Manufacturing-International
COEA	Cost and Operational Effectiveness Analysis
C3I	Command, Control, Communications, and Intelligence
DAB	Defense Acquisition Board
DICE	Defense Advanced Research Projects Agency (DARPA) Initiative on Concurrent Engineering
DIS	Distributed Interactive Simulation
DoD	Department of Defense
DMSO	Defense Modeling and Simulation Office
DSI	Defense Simulation Internet
EDI	Electronic Data Interchange
EMD	Engineering and Manufacturing Development

EXCIMS	Executive Council for Modeling and Simulations
F-SAT	Frugal Satellite
FAADS	Forward Area Air Defense System
FACS	Force Acquisition Cost System
FOFA	Follow-on-Forces Attack
FOG-M	Fiber Optic Guided Missile
ICAM	Integrated Computer-Aided Manufacturing
IDA	Institute for Defense Analyses
IDEF	Integrated Definition Language (formerly Integrated Computer-Aided Manufacturing (ICAM) Definition language)
IHPTET	Integrated, High Performance Turbine Engine Technology
IPPD	Integrated Product and Process Development
LCM	Logistics Capability Model
MIDS	Multi-Functional Information Distribution Systems
MIT	Massachusetts Institute of Technology
MUAV	Maritime Unmanned Aerial Vehicle
NASA	National Aeronautics and Space Administration
NLOS	Non-line of Sight
OSD	Office of the Secretary of Defense
OT&E	Operational Test and Evaluation
PDES	Product Data Exchange Standard
PERT	Project Evaluation and Review Technique
PM	Program Manager
RAMCAD	Reliability, Availability, and Maintainability in Computer-Aided Design
SAFOR	Semi-Automated Forces
SIMNET	Simulator Network
TACCSF	Theater Air Command and Control Simulation Facility
TACWAR	Tactical Warfare (model)

TQM	Total Quality Management
U.S.	United States
VV&A	Verification, Validation, and Accreditation
VTOL-UAV	Vertical Take-off and Landing-Unmanned Aerial Vehicle