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DEFENSE MODELING AND SIMULATION INITIATIVE

1 May 1992

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PREFACE

This paper characterizes the Defense Modeling and Simulation Initiative being developed in response to the Deputy Secretary of Defense's direction to strengthen the use of modeling and simulation.[1] It defines the scope of the Initiative within the context of overall DoD modeling and simulation activities, delineates its objectives, and outlines a general plan of action.

This characterization is an initial one and hence is incomplete in some aspects. For example, in preparing this paper, adequate time was not available to interact broadly with the user community and conduct the analysis necessary to define their needs. Determination of these needs will be a priority item in the period ahead for the Initiative. Similarly, it was not possible to describe the current baseline of modeling and simulation capabilities and programs in any detail.

This paper is presented to facilitate understanding of the Defense Modeling and Simulation Initiative. Given the growing interest and activity in modeling and simulation across the Department of Defense, the characterization provided in this paper will most likely evolve significantly over the next several months.

[1]Deputy Secretary of Defense Memorandum, "Modeling and Simulation Management Plan," 21 June 1991.

EXECUTIVE SUMMARY

The Deputy Secretary of Defense has instituted a major new initiative to strengthen the application of modeling and simulation in the Department of Defense. This Defense Modeling and Simulation (M&S) Initiative pertains to the joint application of models and simulations, and hence is complementary to those efforts carried out within the Services. This paper describes an overall vision for the application of modeling and simulation throughout the Department of Defense and characterizes the role that the Defense M&S Initiative can play toward the realization of that vision.

Recent and anticipated advances in the application of models and simulations have led to the belief that they can make a fundamental and widespread contribution to the development and employment of U.S. military forces. Examples of potential future capabilities include:

- Simulated war fighting environments that allow frequent and realistic joint training spanning several echelons, involving large simulated forces, and bridging large geographic areas.
- Electronic "sand tables" that provide commanders engaged in warfare a realistic means to portray the disposition of friendly and enemy forces and to simulate the consequences of proposed courses of action.
- Simulation testbeds that allow new concepts to be explored and system requirements to be refined before "bending metal" and committing to expensive developments.
- Campaign analysis models that furnish senior defense officials with a tool for budget deliberations that relates individual system effectiveness to the predicted outcome of military campaigns.

Achievement of such capabilities will require a widespread, highly capable, and integrated modeling and simulation environment based upon developments in the areas of architecture, methodology, and advanced technology. Many of the components of the overall modeling and simulation environment will be furnished solely through Service or Defense Agency developments. Given the joint perspective of the Defense M&S Initiative, its role is to support those aspects of the overall environment that tie together the components of individual Services or Agencies or serve to broaden the applicability of those components. For example, the Initiative will

- Promulgate standards to promote interoperability of the components of the modeling and simulation environment.
- Support development of data bases, tools, and methodologies for community-wide use.
- Promote development of a communications infrastructure to support integration of joint modeling and simulation activities.
- Facilitate community-wide coordination and information sharing.

The plan of action for the Defense M&S Initiative (detailed in Chapter 6) emphasizes activity in three general areas – management, policy, and investment. Objectives for each of these three areas have been defined as follows.

Management:

- Establish a DoD-wide management structure to coordinate joint modeling and simulation activities and requirements.
- Promote coordination across DoD components to minimize duplication in modeling and simulation development efforts and to increase productivity through combined efforts.

Policy:

- Develop policy in specific areas necessary to ensure the effective joint application of models and simulations.
- Fix responsibilities to ensure the proper oversight of models and simulations with joint applicability.
- Furnish guidance for the consistent development of modeling and simulation plans by the DoD components.

Investment:

- Formulate and implement a long-range joint investment strategy for models and simulations.
- Identify and fund high-priority investments leading to enhanced joint modeling and simulation capabilities.

The management structure is in place and is centered about the DoD Executive Council for Models and Simulations (EXCIMS), the Defense Modeling and Simulation Office (DMSO), and the DoD Modeling and Simulation Working Group. Policy will be put into effect through the promulgation of a DoD Directive, now in draft form, along with supporting material such as Instructions and Memoranda of Understanding. Investment is being executed as a community-wide process to identify high-value projects for funding that are consistent with the scope of the Defense M&S Initiative. Project submissions have been gathered and put in a priority listing, which has been approved by the EXCIMS. Funding decisions on these projects should be completed during the third quarter of fiscal 1992. Subsequent calls for projects will be made as joint modeling and simulation needs are refined and funds become available.

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Appendices

1. INTRODUCTION

1.1 PURPOSE

There is a growing realization within the Department of Defense that the enhanced and more integrated application of models and simulations can bring significant benefits across the Department. In recognition of the importance of modeling and simulation, the Deputy Secretary of Defense instituted a major new initiative, under the authority of the Under Secretary of Defense for Acquisition, to promote the effective and efficient use of modeling and simulation by:[2]

- Establishing OSD cognizance and facilitating coordination among DoD modeling and simulation activities.
- Promoting the use of interoperability standards and protocols where appropriate.
- Stimulating joint use, high return modeling and simulation investment.

The purpose of this document is to provide a conceptual foundation and lay out a plan for achieving these objectives.

1.2 SCOPE

The initiative instituted by the Deputy Secretary – hereafter called the Defense Modeling and Simulation (M&S) Initiative – refers to the joint application of models and simulations. Thus, the Initiative is intended to complement rather than replace Service activities. In particular, the Initiative will:

- Facilitate coordination and promulgate policy relating to the joint application of models and simulations.
- Support worthwhile programs outside the normal scope of individual Services (e.g., the establishment of infrastructure supporting multiple Services).

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[2]Deputy Secretary of Defense Memorandum, "Modeling and Simulation Management Plan," 21 June 1991.

- Promote extension of ongoing Service developments to multi-Service use where appropriate.

Accordingly, the focus of the initiative is on the joint application of models and simulations, and not on Service-specific aspects.

1.3 OUTLINE OF PAPER

Proper development of a plan for the Defense M&S Initiative requires a broad perspective of modeling and simulation, including their potential applications and future directions. Thus, the first three chapters below (Chapters 2-4) provide this broad perspective, while the last two chapters focus on the specific aims and scope of the Defense M&S Initiative.

In particular, Chapters 2 and 3 provide broad context by discussing, respectively, the types of models and simulations and the national security context in which models and simulations must be applied. Based on that material, Chapter 4 goes on to define a general vision and goals for defense modeling and simulation. Chapter 5 then becomes specific to the Defense M&S Initiative and identifies sets of objectives for the Initiative. Chapter 6 concludes the main body of the document by providing a plan of action for realizing these objectives.

Three appendices are also included to provide additional detail in the areas of architecture, methodology, and technology.

2. CATEGORIZATION OF MODELS AND SIMULATIONS

In order to provide a systematic basis for the discussions of this paper, it is necessary to specify how models and simulations in general may be divided into smaller, logically derived categories. In fact, it is necessary to introduce two means of categorization, from technical and application orientations, respectively:

- By class: Class is based primarily on the technical and physical structure of a model or simulation.
- By use: Use indicates the purpose for which the user community (e.g., training) employs the model or simulation.

Class is specified independent of the community that uses the model. It is possible, and in some cases likely, that a given model will be used by more than one community.

2.1 CLASSES OF MODELS AND SIMULATIONS

While the ultimate test of models and simulations is how well they serve the user, it is necessary to provide some rather detailed technical characterization of them because application of various evolving technologies will differ significantly, depending on the class. Accordingly, models and simulations may be characterized into three broad classes:

<u>Computer Models</u>: Systems and forces and their interaction are primarily represented in computer code. The models can differ greatly in the level of detail of the representation, and there may be some human interaction with the model while it is running.

<u>Manned Weapon System Simulations</u>: Individual weapon systems are modeled (e.g., by a simulator) and are typically controlled by a human operator. Principal emphasis is on the situation where the individual simulations interact together through a distributed network. The archetype of this class is SIMNET.

<u>Instrumented Tests and Exercises</u>: Actual troops, weapon systems, and support systems interact in as real an environment as possible, with instrumentation being

used to collect and distribute status data on the force elements. Activities at the National Training Center are a representative example.

The class "computer models" is complex in its substructure and requires further elaboration. In particular, elements of this class may be described according to three attributes:

Level of Detail: The models may range from those describing individual systems or phenomena to those addressing theater and campaign warfare. In the latter case the individual systems are most likely not explicitly represented in the model.

Human Interaction: Two cases need to be distinguished – (1) closed models, which run to completion given specified input, and (2) interactive models, which allow (or in some cases require) human input at certain decision points while running.

Linkage: Linked models refer to the situation where two or more readily separable models exchange data and operate in such a manner as to form a composite model. The coupling may be either horizontal (i.e., between models of a like level of detail) or vertical (i.e., between models of a different level of detail). The data exchange may span the range from dynamic exchange while the models are running to manual exchange following the execution of a component model.

Hybrid simulations may be formed by mixing elements of the different classes. For example, a computer model may be used to provide the input for the motion of forces in a manned weapon system simulation, thereby reducing the number of human operators required to run a large-scale simulation. Similarly, a real C3 system coupled into an manned weapon system simulation could receive and display information on the simulated systems just as it would real systems, thereby allowing realistic operator training. The opportunities available through hybrid simulations appear to be one of the most promising avenues for further development.

2.2 USES OF MODELS AND SIMULATIONS

The user community is broad, spanning not only those involved in the employment of weapon and support systems, but also those involved in all phases of acquisition of the systems. In particular, the user community has been divided into the following functional areas: education, training, and military operations; research and development; test and evaluation; analysis; and production and logistics.

Some applications of modeling and simulation, broken out according to these functional areas, are as follows:

Education, Training, and Military Operations:	Re-creation of historical battles Doctrine and tactics development Command and unit training Operational planning and rehearsal Wartime situation assessment
Research and Development:	Requirements definition Engineering design support System performance assessment
Test and Evaluation:	Early operational assessment Operational test design Excursion and sensitivity analyses
Analysis:	Campaign analysis Force structure assessment System configuration determination Cost analysis
Production and Logistics:	System producibility assessment Industrial base appraisal Logistics requirements determination

This list is not exhaustive, but it certainly is representative of the many applications of modeling and simulation in the user communities.

An important aspect of the utilization of models and simulations is the application of a model or simulation developed for one particular use to another, possibly quite different use. For example, computer models (e.g., TACWAR), originally developed for force structure assessment, have also been applied for operational planning. Similarly, manned weapon system simulations (e.g., extensions of the SIMNET concept), initially developed in the context of training, are now being considered for use in the development of doctrine and tactics. Furthermore, instrumented exercises, originally implemented for unit training, are now being considered as a component of command level exercises.

The use of a given model or simulation across many applications offers significant benefit by reducing redundant development efforts and more closely integrating the activities of the user communities that are involved.

3. PLANNING CONTEXT

3.1 RELATIONSHIP TO OTHER DOD ACTIVITIES

Three DoD activities are directly relevant to the Defense M&S Initiative:

The DDR&E Science and Technology (S&T) Thrusts. Seven thrust areas have been identified. Modeling and simulation are germane to all these areas and have been singled out as the main subject in one of them. The DDR&E S&T initiative is thus directly relevant to the M&S Initiative. In particular, the same strategic planning factors that guide the S&T thrusts are used in this paper, as given in the next section, below.

The Training and Personnel Systems Technology (TPST) Program. The DDR&E TPST program is concerned with the application of computer- and electronics-based technology for training and readiness. Specific areas of technology application are human factors engineering, simulators and training devices, education and training, and manpower and personnel. Given their direct pertinence to modeling and simulation in general, TPST activities will be tracked for their contribution to the M&S Initiative.

The Corporate Information Management (CIM) Initiative. In large part, the applications of models and simulations are information processing activities. Thus, the CIM initiative with its emphasis on such matters as computer systems architecture, data definitions, software reuse, and rapid prototyping is directly relevant to M&S Initiative. The principal focus of the CIM initiative is policy matters, which will be reflected in the discussions of Chapter 6 (Plan of Action), below.

3.2 STRATEGIC PLANNING FACTORS

Six strategic factors derived from the National Security Strategy promulgated by President Bush pertain to the application of science and technology in general, and hence to modeling and simulation in particular. The following paragraphs describe each of those planning factors and contain a discussion of the relevance of modeling and simulation to the given planning factor.

Global Responsibilities. Continued U.S. global interest and responsibilities imply that the United States must be prepared to project and possibly employ its forces at any of a diverse number of locations worldwide. A drawdown on overseas assets implies less opportunity for U.S. forces to exercise in the regions of interest. Application of modeling and simulation will alleviate this situation by allowing CINCs to train and rehearse their forces in environments that are realistic representations of those to which their forces might be deployed.

Deterrence. Despite the improved relations with the Soviet Union, there remains a continued need for deterrence against proliferating weapons of mass destruction. The strength of U.S. deterrence will depend on the credibility placed in the ability of U.S. systems to defend against and respond to attacks of mass destruction. The active and widespread use of modeling and simulation can help to ensure this credibility, especially for those systems that could never be fully tested in a peacetime environment.

Damage/Casualty Limitation. Heightened concerns about casualties require not only precise weapons, survivable platforms, and accurate target identification systems, but also the need to practice fully with these systems to ensure that their damage and casualty limitation potential would be fully realized in actual practice. Modeling and simulation can be an important contributor in all these aspects because it supports both system development and crew/unit training.

Constrained Budgets. Smaller force structure, less funding for modernization, and possibly reduced operational tempo imply the need for better training, more cost-effective systems, a more productive and responsive defense industrial base, and more creative use of technology insertions for system upgrades. Modeling and simulation can help in all these areas – for example, their greater use in weapon system design and manufacturing can lead to enhanced productivity from defense industries; furthermore, they allow the affect of technology insertions to be explored before commiting to the actual use of the technologies in system upgrades.

Technology Acceleration. Developments in microelectronics, computers, sensors, communications, and worldwide and local networks are all accelerating at unprecedented rates, particularly in the commercial sector. Leading and harnessing this ongoing "information revolution" to serve national security needs should be central to DoD's science and technology strategy. This, in fact, is the essence of modern modeling and simulation developments – they are predicated and build upon the recent and anticipated advances in computer and information science and technology.

Technology Diffusion. The worldwide nature of the technology revolution has two important implications for the United States: it must expect that future adversaries will have capable and sophisticated weapon systems, and it must stay at the leading edge of technological development. In this regard, modeling and simulation support both the development of advanced U.S. systems and allow their exercise against projected threats. Furthermore, the United States is the world leader in modeling and simulation capability, and thus should work actively to maintain that advantage.

In summary, the United States today faces great uncertainty due to a rapidly changing world. New conflict scenarios visualizing operations at any of a large number of locations worldwide, at varying levels of conflict, and in conjunction with new weapon systems will lead to the development of new operational concepts. Modeling and simulation, drawing on existing and new technology, must be able to support test and validation of these concepts, provide the means for war fighting rehearsals and preparation of forces, and allow commanders and their staffs to design, assess, and visualize the simulated consequences of execution of their campaign plans. Similarly, modeling and simulation must be prepared to support all phases of the acquisition process that will be used to provide the new and upgraded weapon systems for employment in these potential future conflicts. Finally, in light of the constrained budgets, the modeling and simulation community will have to be more resourceful with available assets and, at the same time, be ready to respond to an increased demand for its services.

4. MODELING AND SIMULATION VISION AND GOALS

4.1 VISION

The discussion of the two previous chapters indicates the fundamental and widespread contribution that modeling and simulation can make to the development and employment of U.S. military forces. This idea can be summarized in the following statement of the vision for applying modeling and simulation formulated by the EXCIMS:

> *Defense modeling and simulation will provide readily available, operationally valid environments for use by DoD components*
>
> - *to train jointly, develop doctrine and tactics, formulate operational plans, and assess war fighting situations,*
> - *as well as to support technology assessment, system upgrade, prototype and full scale development, and force structuring.*
>
> *Furthermore, common use of these environments will promote a closer interaction between the operations and acquisition communities in carrying out their respective responsibilities. To allow maximum utility and flexibility, these modeling and simulation environments will be constructed from affordable, reusable components interoperating through an open systems architecture.*

To be more specific, one can postulate a future in which models and simulation furnish capabilities as illustrated in the following examples:

> Simulated war fighting environments will be constructed that allow the CINCs and Services to train the forces, plan operations, and assess the status of actual operations. The training will be joint, span several echelons, involve large simulated forces, bridge large geographic regions, and involve senior commanders as well as units and individual soldiers. The planning support will apply to the generation of theater-level operation plans, the development of more specialized unit plans, and the evolution of doctrine and tactics. Status monitoring will be based on electronic "sand tables" on which the disposition of friendly and enemy forces can

be realistically portrayed and the consequences of proposed courses of action simulated.

Similar environments will support the many phases of the acquisition process, from initial concept development to actual production of new systems. Simulation testbeds will allow new concepts to be explored and system requirements to be refined before "bending metal" and committing to expensive developments. Operational testing will be augmented by embedding live tests in a broader simulated environment that will allow for more comprehensive system tests. Campaign analyses will be conducted to support senior defense officials in their decision making responsibilities (e.g., in the DAB or PPBS process). System logistics and maintenance demands will be fully explored to provide a realistic view of system life-cycle costs.

Furthermore, use of these environments will bring the operational and acquisition communities closer together. Simulated tests of proposed new systems or technologies will allow the doctrinal and tactical implications of the new capabilities to be explored prior to any procurement or prototype development. Similarly, new means for employing or modifying existing systems may be readily explored. Continued testing of systems in operationally realistic simulated environments during system development will ensure that the final system configuration corresponds as closely as possible to operational needs.

4.2 GOALS

A wide variety of activities is necessary to achieve the vision described above. Consequently, a set of goals is necessary to guide this activity. To that end, six goals have been identified as central to realizing the vision: applicability, integration, availability, flexibility, realism, and openness. The following paragraphs define and discuss each of these goals.

Applicability. Support the missions of DoD components as fully as possible.

Discussion. The DoD components include the functional communities – Education, Training, and Military Operations; Research and Development; Test and Evaluation; Analysis; and Production and Logistics – as well as the organizational elements – the CINCs, the Services, the Joint Staff, and the Defense Agencies. Each of these components has its particular needs. Widespread efforts should be made to ensure that modeling and simulation support the needs of each of these communities as broadly and deeply as possible.

Integration. Promote close interaction among DoD components to serve their individual needs and overall DoD needs.

Discussion. It is not enough to serve the needs of the individual components alone. Indeed, modeling and simulation can enhance the interaction between components, e.g., between two Services or between the research and development and the operational communities. The result of this closer interaction will be, for example, more effective training and the realization of systems that better satisfy the operator's needs.

Availability. Be readily available to users at their home stations throughout the United States and worldwide.

Discussion. Modeling and simulation capabilities must be available to the users at their normal place of work, be it the research laboratory, the manufacturing facility, or the home base of military forces (or their deployed site in the case of an exercise or operation). Only in this way will modeling and simulation be able to support fully the needs of the users.

Flexibility. Adapt readily to new scenarios and allow for wide ranges of excursions.

Discussion. Flexibility has two dimensions. First, the models and simulations must accommodate a wide range of scenarios in order that the wide range of potential contingencies and their concomitant uncertainties can be addressed. Second, the models and simulations must allow new and novel uses of systems to be explored. This second quality will especially be of benefit when developing the doctrine and tactics to accompany a new or proposed weapon system.

Realism. Represent systems, behaviors, and environments to reproduce real-world results as accurately as needed.

Discussion. Models and simulations must obviously produce credible results, but there are many different aspects to the matter. For example, for computer models, this credibility means attention to verification, validation, and accreditation procedures. For distributed manned simulations, it means both attention to visual fidelity and an understanding of the limits that existing fidelity places on the implications that can be drawn from the simulation. In general, realism should not be regarded as an end in itself, but rather as tied to the needs of particular applications.

Openness. Allow the use and interaction of the full range of models and simulations, both existing and future.

Discussion. Models and simulations may be broken into three general classes: "traditional" computer models, distributed manned simulations, and instrumented tests and exercises with actual troops and weapons systems. Different applications will require members from different classes; in some instances elements from one class or from different classes will need to interact with one another. As a consequence, no one class is singled out as best and all will be used. However, the interaction among models and simulations means that, where necessary, they must interoperate with one another.

5. OBJECTIVES OF THE INITIATIVE

Chapters 2-4 provided general discussion on the state and direction of defense modeling and simulation. Against that backdrop, this present chapter now turns to the specific objectives of the Defense M&S Initiative, which, as indicated in Chapter 1, is concerned with enhancing the joint aspects of modeling and simulation. General objectives are first specified, followed by a more refined set of technical objectives.

5.1 GENERAL OBJECTIVES

The general areas addressed under the Defense M&S Initiative can be characterized as management, policy, and investment. Objectives have been specified for each of these areas, as follows.

Management:

- Establish a DoD-wide management structure to coordinate joint modeling and simulation activities and requirements.
- Promote coordination across DoD components to minimize duplication in modeling and simulation development efforts and to increase productivity through combined efforts.

Policy:

- Develop policy in specific areas necessary to ensure the effective joint application of models and simulations.
- Fix responsibilities to ensure the proper oversight of models and simulations with joint applicability.
- Furnish guidance for the consistent development of modeling and simulation plans by the DoD components.

Investment:

- Formulate and implement a long-range joint investment strategy for models and simulations.

- Identify and fund high-priority investments leading to enhanced joint modeling and simulation capabilities.

These objectives provide the starting point for the plan of action given in the next chapter.

5.2 TECHNICAL OBJECTIVES

While the general objectives given above are necessary for broad context, they do not indicate the particular substantive technical areas that will be addressed under the Initiative. That is, achievement of the vision and satisfaction of the goals enunciated in Chapter 4 require, at the technical level, a widespread, highly capable, and integrated modeling and simulation environment. The technical objectives specified below define the technical contribution that the Initiative will make to achieving that environment.

To realize the modeling and simulation environment, three areas of development must be addressed (Appendices A-C provide more detail for each area):

Architectural Development. The wide and diverse use of modeling and simulation requires that overall architectural structures be put into place to allow interoperability and the sharing of assets. The specification of interface standards will be key to the realization of these architectures. It must be recognized, however, that the demand for interoperability and the imposition of standards are not an end in themselves; rather, they should be imposed only where there is a clear need to support the user communities.

Methodological Development. Explicit recognition must also be given to the conceptual basis for developing models and simulations and to the manner in which they are applied. Relatedly, the credibility of the applications and the quality and completeness of the representations expressed in the models and simulations must be addressed. A sound methodological basis will allow useful, new applications of modeling and simulation to be developed.

Advanced Technologies. Architectural and methodological development are overarching themes that include several technological elements, but there are additional, key technologies supporting modeling and simulation that must be explicitly addressed. Representative areas are computing hardware, networking, graphics displays, and terrain/environment representation.

Many of the components of the overall modeling and simulation environment will be Service- or Agency-specific developments (e.g., new combat models or simulators). The Defense M&S Initiative supports those aspects of the overall environment that tie together the components of the individual Services and Agencies or serve to broaden the applicability of those components. To make more specific the activities that will be promoted under the Initiative, the following set of objectives has been defined for it.

Architectural Development:

- Promulgate standards to support development of open modeling and simulation architectures.
- Promote development of a communications infrastructure that will support the wide availability of modeling and simulation capabilities and allow the closer integration of modeling and simulation activities.
- Identify and support opportunities for enhancing interoperability among the models and simulations of the DoD components.

Methodological Development:

- Develop mechanisms to facilitate the sharing of information within the modeling and simulation community so as to foster cooperation and minimize duplicate development.
- Promote common-use tools to facilitate the development and application of models and simulations and to make the interpretation of their results easier.
- Foster means to enhance model and simulation credibility and maintenance, including configuration management and verification, validation, and accreditation.
- Encourage innovative new uses of models and simulations, including the extension of individual models and simulations to support the needs of multiple DoD components.
- Promote the compilation and appropriate distribution of common-use data bases.

Advanced Technologies:

- Collect and systematize the needs of the user communities for new or enhanced modeling and simulation capabilities.

- Identify and support those technologies that offer the most potential to satisfy outstanding user needs, building as appropriate upon those technologies that are commercially available.
- Support the transition of promising technologies from the research stage to use by the DoD components.

These technical objectives pertain to all areas of activity for the Defense M&S Initiative – management, policy, and investment. For example, interoperability requires investment to support development of the proper interfaces among models and simulations, but policy and management are also required to ensure that the Defense components adopt and support the appropriate interface standards.

The plan of action given in the next chapter will be structured according to the three main areas of activity – management, policy, and investment – but the themes raised in the above technical objectives will appear repeatedly in the discussions of those areas.

6. PLAN OF ACTION

6.1 MANAGEMENT

The management structure for the Defense M&S Initiative is in place. Overall responsibility lies with the Under Secretary of Defense for Acquisition. Key elements of the management structure are the DoD Executive Council for Models and Simulations (EXCIMS), the Defense Modeling and Simulation Office (DMSO), and the DoD Modeling and Simulation Working Group (MSWG).

The EXCIMS is a board chaired by the Director of Defense Research and Engineering, and has senior representatives from the Services, Joint Staff, and OSD. It meets for the purposes of providing general guidance, formulating policy, and recommending project approval.

The DMSO is composed of five individuals with an O-6 level director. It serves as the executive secretariat to the EXCIMS and provides the full-time focal point for the Defense M&S Initiative. The MSWG, which is chaired by the Director of the DMSO, is composed generally of GS-15/O-6 representatives from the Services, Joint Staff, Defense Agencies, and OSD offices. This working group meets formally approximately monthly, and on an individual basis much more frequently, for the purposes of preparing material for the EXCIMS, executing a project solicitation and priority ranking process, and reviewing policy issues.

The activities of the DMSO and MSWG are also supported by a series of functional and technical working groups, thereby ensuring broad representation of defense and technical perspectives.

6.2 POLICY

A large set of policy issues have been raised for discussion, including:

- Promulgation of standards for the interoperability of models and simulations
- Modeling and simulation planning guidance for Services and Defense Agencies
- Use of modeling and simulation in the defense acquisition process

- Means to satisfy CINC needs for modeling and simulation capabilities
- Procedures to minimize duplicate modeling and simulation development
- Development of multi-use models and simulations to serve across functional communities
- Configuration management of jointly used models and simulations
- Validation, verification, and accreditation of jointly used models and simulations
- Releasability of data
- Application of Corporate Information Management (CIM) policy
- Portability and reuse of modeling and simulation software

At the current time a draft DoD Directive (or Instruction) addressing modeling and simulation policy has been prepared and is being coordinated at the working level and will later be forwarded to the EXCIMS. That directive will provide broad policy that will be followed later by more specific means (instructions, memoranda of understanding, etc.) for implementing the particulars of the policy.

6.3 INVESTMENT

The investments made under the Defense M&S Initiative must support user needs and at the same time be consistent with the scope of the Initiative. This is achieved by defining a set of investment categories appropriate to the Initiative and by having proposed projects reviewed by groups representative of the user communities.

In terms of broad principles, the investment strategy for the Initiative can be characterized as follows:

- Support the broad, overall vision for modeling and simulation within DoD.
- Fund projects within the scope of the Defense M&S Initiative.
- Seek Service and Defense Agency commitment through participatory funding for projects they submit.
- Do not replace or duplicate existing Service requirements definition or acquisition processes.

The Initiative's purpose in funding projects is to support programs outside the normal scope of individual Services and extend ongoing Service programs to multi-Service use. Hence, there is a strong emphasis in this investment on interoperability, infrastructure, and other items of common use. In short, these are the items consistent with the scope of the Initiative that support the broad vision of a widespread, highly capable, and integrated modeling and simulation environment.

In particular, five investment categories have been defined for use of the funds allocated to the Defense M&S Initiative. These categories along with representative projects appropriate for funding are:

- **Interoperability/Standards Development.** Funded activities would include the development of interface standards and the incorporation of these standards into Service models and simulations.
- **Communications Infrastructure.** Funding would support, for example, the transition of advanced communication networks from research to operational stage to allow the high-capacity interconnection of Defense laboratories, Service schools, training sites, and test ranges, as well as other appropriate facilities.
- **Information Sharing.** Representative projects include an information clearing house to serve all of the defense modeling and simulation community as well as other means for enhancing interaction among modeling and simulation practitioners.
- **Common Tools/Methodologies.** Appropriate tools and methodologies include those with application to more than one defense component that would aid in the construction of models and simulations, the interpretation of their results, and the enhancement of their credibility.
- **Common Databases.** Representative databases include ones applying to the needs of more than one defense component that address, for example, friendly force and weapon characteristics, threat characteristics, and environment and terrain.

Based on these categories, the EXCIMS approved a statement of investment guidance:

The explicit goal of the Defense M&S Initiative is to promote the efficient and effective use of models and simulations at the Joint and DoD levels. To accomplish this goal the following objectives will guide investments:

- *Promulgate standards to promote interoperability of the components of the modeling and simulation environment.*
- *Support development of databases, tools, and methodologies for community-wide use.*
- *Promote development of a communications infrastructure to support integration of joint modeling and simulation activities.*
- *Facilitate community-wide coordination and information sharing.*

A process has been carried out for collecting proposed projects from the Services and Defense Agencies, consistent with the above investment guidance, for funding under the Defense M&S Initiative, using funds from the FY 1991 and 1992 budgets. In order to ensure the appropriate user perspective, the collected projects were grouped according to the five functional areas – education, training, and military operations; research and development; test and evaluation; analysis; and production and logistics – and were ranked in priority order within each of those functional areas by representatives from the functional community. The projects were then ranked in overall priority order by the MSWG and submitted to the EXCIMS, who approved the ranking. Funding decisions on these projects are expected to be completed during the third quarter of FY 1992. In addition, a feedback mechanism is being built into the project approval process so that the utility of the funded projects can be monitored.

Project submissions will again be considered for funds allocated for the Initiative in FY 1993. The process used for these funds will evolve from the current process based on the experience gained in allocating the FY 1991 and 1992 funds and on analyses conducted in the intervening period. For example, more explicit guidance on project areas most requiring attention might be provided to the submitting agencies. In fact, in the course of deliberations for the use of FY 1991 and 1992 funds, a set of relevant areas not addressed by the submitted proposals was identified. With respect to FY 1994 funding, steps are underway to prepare a POM submission for the Initiative for the FY 1994 budget.

6.4 FUTURE ACTIVITIES

The activities discussed above in the areas of management and investment are ones that, for the most part, have been completed or will be completed in the near term. The policy issues should be defined at a high level in the near term, although their implementation will stretch out longer. There are still other activities that will begin in the near term and continue for some time afterwards. These activities include:

- **Definition of community-wide modeling and simulation needs.** At the present time there is no one unified statement of modeling and simulation needs and deficiencies across the DoD Such a statement is necessary so that the DoD can progress toward the vision of highly capable modeling and simulations environmer.s in a coordinated and efficient manner. Representatives of the DMSO will work with members of the MSWG and representatives of the functional communities to prepare this statement of needs and deficiencies, which will then be reviewed with the EXCIMS.

- **Preparation of defense modeling and simulation master plan.** After specification of needs and deficiencies, a department-wide process will be instituted to prepare a plan for satisfying those needs and resolving the deficiencies. Guidance will be provided to each of the DoD components to prepare its master plans to articulate its overall goals and programmatic initiatives. A DoD-wide master plan will be prepared that draws upon these individual master plans.

- **Integration with S&T Thrust 6.** The sixth of the seven Science and Technology thrusts (briefly noted in Chapter 3) is addressing training and readiness, particularly as can be enhanced through use of advanced simulation technologies. This thrust activity is developing a series of demonstration projects to be executed over approximately the next ten years. Since these demonstrations will involve those infrastructure and other elements of central interest to the Defense M&S Initiative, integration of relevant Initiative and Thrust 6 activities is required. In fact, these two efforts are already loosely coordinated and that coordination will now be made more specific.

- **Standards and interoperability planning.** The promulgation of relevant standards and achievement of appropriate interoperability are key aims of the Defense M&S Initiative. To some extent these matters are addressed through project funding, but there are broader issues to treat such as the standards to be addressed, the standards bodies to coordinate with, and the sources of personnel to carry out these coordination activities. Thus, a planning activity will be carried out to address the overall approach to standards and interoperability.

EXCIMS guidance will be sought on each of these four areas, as well as on any additional activities they want pursued.

APPENDICES

APPENDIX A

ARCHITECTURAL ASSESSMENT

Within DoD a large amount of work on a variety of modeling and simulation (M&S) projects has generated a multitude of computer code, with different designs and language implementation but frequently oriented toward the same goal. The Defense M&S Initiative seeks to coordinate different DoD models to allow a degree of interoperability between existing models and to provide a framework for the seamless integration of new models. This approach builds on progress in industry open architecture solutions and DARPA-sponsored technology development in communications and hardware areas. However, higher level application interaction has been slow in coming and is impeded by a number of factors. First, there has been no requirement compelling enough to overcome the initial expense and programming difficulties of designing interoperable code. Second, models are usually built to answer specific questions concerning particular studies or system developments, rather than being generalized for reuse or evolutionary growth in capability. One of the major goals of the Defense M&S Initiative will be to define an architecture spanning the entire DoD activity, and to foster the seamless integration of new models into combat simulations.

A.1 DEFINITIONS

A.1.1 Definition of Architecture

In terms of large DoD combat simulations, the term "architecture" refers to information formats (syntax), information content (semantics), and physical connections which join one model or simulation to another. Any architectural relationship must have at least the first two attributes–some information format and content. In the case of synchronized, real-time simulations a direct physical connection is probably necessary. However for analytic models where the output of one simulation may be magnetic media or printed data, off-line editing and manual input into a second model may be a satisfactory interface. Description of any form of an architecture immediately becomes a matter of a design language which is commonly understood among all builders (e.g., blueprint drawings) and interface standards (e.g., specification parameters for size of bolt, pitch of threads, and torque limit). For present purposes "architecture" can be defined as a collection of interface standards, a common design language, and a conceptual framework for orienting discourse about M&S issues.

A.1.2 Definition of Interoperability

Two or more models or simulations are said to be interoperable if information flows between or among them at a rate sufficient to support normal operations of specified users. This definition recognizes that interoperability is, by nature, situation dependent. If an analyst can conveniently consume several days to translate the output file from one model to be an input to another model and still support schedule constraints of his work, then the criterion for interoperability is met. On the other hand, if a simulation of air warfare when integrated with a ground warfare model slows down the progress of the battle to less than the real-time needs of the training force, then a condition of interoperability would not exist.

A.1.3 Relationship of Architecture and Interoperability

Any description of the current or potential future architectures of the DoD modeling and simulation infrastructure must address two important issues. The first is to highlight those attributes of simulations or models which pertain to evolution toward greater integration among them. Such attributes should provide understanding of how a wider framework for interoperability might be established or how individual elements might be modified to conform to interface standards. These attributes should address the problems of interface definitions, model resolution and scope, time handling, environmental definitions, network control, and user interaction. Although the architecture dictates the way that models should behave in the overall framework, it does not dictate the methods of construction of the different models. A successful architecture will be flexible enough to accommodate a wide range of models as long as it properly handles the time and environmental constraints of the common battlefield, and controls information flow among the elements of the aggregate simulation.

The second issue is to describe M&S architecture in terms meaningful to model users as well as developers. Given the DoD investment in M&S, care should be taken by model developers to discuss architectural implications for simulation behavior from a user's frame of reference. The user of a model is an integral part of the man-machine dialog , and the interoperability problem begins with the need to translate freely between a user's conceptual framework and that of the model developer. The approach to describing an M&S architecture must explicitly include parameters important to all of the functional user

M&S architecture must explicitly include parameters important to all of the functional user communities and give visibility into opportunities for integration across their current boundaries.

A.2 ARCHITECTURE VARIABLES WITHIN CLASSES OF MODELS AND SIMULATIONS

It is convenient to break architectures into three broad classes, where the nature of the interactions between the computer programs and the human user fall into natural separations. The first class is the rather broad category of computer models. In this class, the control and progress of the simulation is with the computer. The human inputs the scenario and the simulation runs largely untouched. In the next class, manned weapon system simulations, the computer and the operator share control. The user runs and guides a weapon system through an environment that is "created" by the computer. In the third class, instrumented tests and exercises, the total control of the simulation is with the human participants. The computer supplements the exercise by keeping score and simulating some of the weapons used. The issues of interoperability vary within each class and solutions for intra-class integration may be extended to the problems of integration across classes:

A.2.1 Computer Models

This class is least constrained by the "real-world" and consequently exhibits the widest variation of characteristics such as time management, information input/output (I/O) format, network control, and user interaction. Models in this class may handle time either as a control variable, a data variable, or a constant as in the case of a static Computer-aided Design (CAD) model. Time-driven simulations are controlled by some proportional synchronization to the computer clock cycle. If processing power is not stressed, they may simulate events at faster than real time or they may be used to analyze a rapid sequence of events by slowing them down. Event-driven simulations are controlled by, as the name implies, a series of events imitating a chain of cause and effect. Time is only recorded as a data variable which always increases but may have many discontinuous jumps. Although these models can be run in real time, they are often run "off-line" or in a batch mode where time is used as an independent variable but there is no requirement to produce an output with any predictable relationship to real time. Information I/O varies from reading and writing files to processing transactions in a relational data base, object-oriented data base, or semantic knowledge base. User interface can vary from tabular printouts to synchronous display of two- or three-dimensional graphics and limited keyboard or pointer input from human operators. The most difficult architectural variable to address is consistency among data models. Combat simulations encompass a wide variety of information and a common framework for communication will be difficult to establish.

The problem of integrating these diverse models requires the introduction of a different concept in interoperability, that of resolution, both horizontal and vertical. On one hand there is a horizontal problem integrating simulations conducted on the same order of battle, for instance, battalion level or platoon level. In this case the models must use the same terrain, the same environment, and handle any possible differences in time management. In the case of vertical resolution, the problem of scale and level of detail must be addressed. Simulations on one level must pass data to next highest level of simulation, and the architecture chosen must define these data paths and flow. Research in the area of horizontal resolution has resulted in ALSP, Aggregate Level Simulation Protocol. ALSP inserts a small piece of code into each of the participating simulations and then presents an overall structure to control each of the simulation models. It presents one approach to the problems of time management and data passing. There have been other approaches to the problem, in the form of DICE and Data_Bus. A major task of the M&S Initiative will be a peer review and evaluation of these different approaches to the problem of horizontal interoperability. The development of an architecture suited to interoperable simulations will depend on the development currently underway and the lessons learned from these attempts.

A.2.2 Distributed Manned Simulations

One type of DoD simulations is "soldier in the loop" simulators which provide individuals or teams the opportunity to operate in an artificial battlefield created by computer-based simulation software. The most important constraint associated with this type of simulators is the need to support a high rate of information input through the human-computer interface which must operate in real time. When a large number of simulators are linked together, the constraint on data bandwidth transmitted through the network becomes significant. The most direct method of implementing real-time models is to synchronize all events to a single clock. However, this becomes unworkable in the case of distributed simulations running over a Wide Area Network (WAN). As long as causality can be maintained by processing all events in their normal sequence, then the need for precise synchronization can be relaxed. One architectural approach pioneered by the DARPA SIMNET program has been to satisfy the high information rates local to each simulator by a dead-reckoning algorithm and to update other nodes at the lower data rates supported by the network.

This SIMNET approach capitalizes on distributed processing, advanced software, high capacity networking, and advanced computer graphics technologies to create a first step in a virtual battlefield for training, experimentation, and system development. SIMNET demonstrated the technical feasibility of networking large numbers of individual platform simulators and supporting interoperation of those simulators through standardized message exchange protocols. In addition, through the development of Semi-Automated Forces (SAFOR) SIMNET further demonstrated the potential for representation of larger numbers of platform-level battlefield objects in software under the control of live commanders, thus reducing the manpower requirements for larger scale deployments with SIMNET.

Based on SIMNET success, the concept and technology are making the transition to operational use as part of the Army's Distributed Interactive Simulation (DIS) initiative. On the technical side, DIS is based on a distributed message-passing protocol-based architecture for simulation interoperability. The participating simulators are all real-time simulators and the DIS exchanges are conducted in real time as well. Individual simulators locally provide the computing capability to represent detailed aspects of their internal characteristics and the ability to exchange public information about changes in their state and events with external consequences. Each simulator also maintains a local (dead reckoning) model of itself and all other platforms on the shared battlefield to support continuous interaction among objects between message exchanges. Interaction is based on broadcast of messages, with individual simulators responding to those messages with local impact.

As DIS evolves, there continue to be technical issues to be addressed. First, as larger numbers of objects, both "live" and SAFOR, are incorporated, more efficient means of data distribution and data filtering will be required to manage the resulting message traffic and the demands on local processors to model other platforms on the battlefield. These are technical issues of particular interest to the ongoing DARPA Intelligent Gateway/Smart Switch (IGSS) program. Second, as new and diverse platform simulators are integrated into DIS, attention will be focused on maintaining congruency of the battlefield environment across simulations, especially as environmental features become "active" and are treated as object themselves.

Principles of the DIS architecture has already been extended into the class of computer models to support aggregate level simulation interfaces with the development of the Aggregate Level Simulation Protocol (ALSP), discussed earlier. ALSP adopts the basic architectural principles of DIS and provides added capabilities in time and data management to support the technical characteristics of current aggregate level simulations. Interfacing fine grain simulations, as represented in DIS, with more coarse grain simulations as supported by ALSP, is an area of research interest, and represents the first real attempt to develop interclass connections, integrating computer models into manned simulators.

A.2.3 Instrumented Tests and Exercises

Instrumented tests and exercises are performed in various test facilities and exercise areas that are designed specifically for these purposes. These facilities have been designed separately, and when they were designed there was no perceived need for them to interoperate with each other or with other types of simulations not directly supporting the facility. In some cases common instrumentation packages are used, but often custom systems have been developed for each facility. Thus, there is little interoperability either between facilities, or between test and exercise facilities and other types of simulations. However, there are two general areas of current interest that may result in increased interoperability within this class and one area which extends to other classes (treated in the next sections).

First, different facilities could interoperate to produce training or testing on a larger scale. For example, air, ground, and sea facilities could interoperate to produce a theater-level exercise. At present, the implementation plan has not been laid out, but the concept itself may help provide a framework for actual interoperability improvements. Linking training facilities to command simulation facilities such as the Warrior Preparation Center, or to large scale computer simulations, could provide an interface to indirectly link separate facilities.

Second, new measurement systems may result in more commonality and thus more interoperability among instrument packages. For example, there is increased use of GPS satellites to provide time, space, and position information. Addressing the problem of increased bandwidth for the WAN so that larger numbers of players may be accommodated is another avenue for evolving towards a more interoperable architecture.

A.2.4 Inter-Class Interoperability

Efforts are currently proceeding to attack the problems of interoperability within the three architectural classes outlined above, but these must be extended to provide a framework of connectivity between classes. Instrumented tests and exercises are limited by the size and scope of test ranges, but could be included in a larger context by the use of computer models to provide a virtual battlefield to encompass the exercise. Large armored divisions could be added to test exercises through connection of the test ranges to SIMNET. And computer models of new weapon systems could be incorporated and tested in combat situations through simulation early in the acquisition cycle, when the designs could be modified to better reflect real combat problems. For example, there is a program to coordinate the use of a computer model (EADSIM), a manned simulation (TACCSF), and field tests in a Joint Air Defense Operations/Joint Engagement Zone Test. Beyond this, there are concepts to provide real-time linkages including a current study of how to use SIMNET (DIS) messages in the Army's Mobile Automated Instrumentation Suite (MAIS) now under development.

The problems of integrating these architectural classes are very similar to the problems found within the classes, that of incompatible hardware, terrain models, environmental models, message passing, and time management. However, these problems will be magnified many fold. There will be problems of integrating virtual battlefield objects with real troops in exercises. There will be problems of integrating event-driven computer models with time-driven manned simulations. And the computer and network hardware requirements to pass data at the necessary levels will require a new generation of technology.

Efforts in this area will continue primarily on an ad hoc basis until enough experience is developed to modify the overall architectural guidelines. The M&S community, through DMSO, will continue to monitor, evaluate, and detect the emerging trends which will eventually allow the overall integration of the three architectural classes.

A.3 CURRENT STATE OF INTEROPERABILITY

Historically M&S has been developed ad hoc and in reaction to solving program specific design problems. Due to problems of programmatics, both in time and funding, program-specific designs have rarely been extended to general solutions with an approach to a wider context.

A.3.1 Lack of Standards

Not only has the history of ad hoc development of M&S prevented convergence at the top level towards common representation of combat dynamics but also the fast pace of R&D in the general fields of information and computer technology has inhibited the growth of interface standards from the bottom physical layer upwards. While there is much activity and publicity for such initiatives as OSI, CALS, PDES, GOSIP, the standardization process can only be effective if implemented by industry and this depends on the slowly moving process of negotiated consensus. To be successful standards must emerge from a marketplace which is sensitive to customer needs. Standards issued unilaterally with no connection to a large production base will be ignored and rapidly made obsolete by the fast rate of technical progress.

The landscape of the information services world is beginning to be populated with voluntary standards particularly in the areas of networking, where examples such as IEEE 802.3 Ethernet and ASC X3T9.5 Fiber Optic Distributed Data Interchange (FDDI) have promoted technology transition. The rapid growth of the market for LAN products and development of fiber optic networks for high bandwidth connection between computers and mass storage devices has confirmed these efforts to be successful. It is in the higher layers of the OSI reference model, however, that the lack of progress in industry standards has been most evident. In some cases there has been convergence to two or three proposed standards competing for the commercial marketplace's favor, such as the competition between the X-Windows Graphic User Interface frc n Sun Computer (Open Look) and from the Open Systems Foundation (MOTIF). Nevertheless, the critical issue is whether standards emerging from the commercial market are adequate to support the needs of the DoD M&S users. Testing of implementations of the GKS and PHIGS formats have shown them to be inadequate for application to distributed manned simulators, and in the area of network protocols commercial industry is not addressing the needs of DoD M&S for multicasting and real-time control. As a result of the DARPA-sponsored SIMNET and DIS developments, a proposed standard for real-time protocols applicable to distributed manned simulators has been submitted to IEEE, but the question remains whether military users will specify adherence to DIS protocols in their individual projects.

A.3.2 Vision of Future Environment

A visionary goal for a future modeling and simulation environment is complete horizontal and vertical interoperability of simulations of all types. Horizontal interoperability would mean that simulations of comparable systems, or at comparable conceptual "levels," could interoperate. For example, a computer simulation of a tank could fight against a manned simulator, or these two simulations could fight together against actual vehicles at an instrumented test facility. Vertical interoperability would mean that simulations at different conceptual levels, of greater and lesser aggregation, could interoperate. For example, a simulation of an armored battalion could incorporate any of these individual tank simulations, and in turn could be a part of a division or higher level simulation.

At this time it is not clear how far and how fast this vision will carry the M&S community. Current efforts to increase interoperability address portions of this overall vision, but much work remains to be done to define all of the needed interface standards.

A.3.3 Process of Establishing Standards

As Carl Cargill points out in "Information Technology Standardization" the trend over the last decade has been decreasing use of government regulatory power to enforce industrial standards. There is particular difficulty with using regulation to force changes and Cargill asserts that if "an unpredictable arena is regulated, the very act of regulation will introduce abnormalities into the environment making it still more unpredictable." Historically, the more effective approach to promulgating standards has been through voluntary organizations associated with engineering professions such as ASTM, ASME, IEEE and EIA. These voluntary organizations have no power to dictate change and must lead the market to a consensus standard for the mutual benefit of producers and customers alike.

In understanding the operation of consensus standards one must distinguish between two categories of standards-creation activities–ones that by negotiated agreement plan to change the industry and ones that reinforce existing patterns. The former are usually conceptual and revolutionary in nature and the latter are evolutionary in nature and usually involve implementation of a specific product or its upgrade. Unfortunately, the fast pace of development in the information technology arena has resulted in product implementation standards being less effective as they are often obsolete by the time they are issued. Consequently, there has been greater desire on the part of producers to use the anticipatory nature of conceptual standards or the open-ended character of process standards.

The Defense M&S Initiative will monitor and assess emerging standards from the marketplace to determine their applicability to DoD problems. It could also consider developing an investment strategy to extend commercial standards into the M&S community.

A.4 ISSUES

A set of primary issues concerning architecture and interoperability have emerged. The first is the need to compare architectural attributes of various models within and across the three classes. The objective is to describe the generic framework within which the interoperability performance of alternative architectures can be evaluated. This framework should not be tied to a snapshop of the current state of M&S infrastructure but should facilitate the understanding of alternative paths of how architectural interfaces might evolve through time. Once these attributes have been clearly described they would be also factored into the project evaluation process for the Defense M&S Initiative.

The second major issue is whether there are effective strategies by which the Initiative might accelerate the emergence of the voluntary industry standards which make M&S architectures more interoperable. Is there a combination of mechanisms which, on one hand, significantly improves cooperative information flow in the planning and conceptual phase between M&S producers and customers and, on the other hand, provides a stable, well-funded demand pull by informed users who are able and willing to conduct fair, technology-based competition with incentives to superior producers?

The third major issue is how to bring a powerful message concerning the benefits of interoperable M&S architecture to the various managers and decision makers throughout DoD. This amounts to assembling case history and quantitative evidence of how those who are willing to sacrifice some habits, conveniences, and even some up-front capital investment can reap long-term rewards in acquisition cycle acceleration, product reliability, maintenance economies, training effectiveness, and combat readiness for joint operations.

A.5 ARCHITECTURE, STANDARDS, AND INTEROPERABILITY INITIATIVES

The Defense M&S Initiative will consider the following projects to understand M&S architectural attributes of the current infrastructure and its evolutionary alternatives, describe the dynamics of the voluntary standards process, study the impact of government policy on accelerating emergence of standards, and develop a strategy for prioritizing and incentivizing interoperability improvements within DoD including optimizing the interaction between DoD and developments in the commercial computer and information sciences world.

1) Develop a preliminary reference model which could be generalized to the entire DoD M&S infrastructure. Study and integration of published knowledge on

architecture, measures of interoperability, protocols, heterogeneous databases, translators and time management (various clocks, various levels of interactions) will establish a framework which can be used the terms of reference for the peer reviews discussed in the next paragraph.

2) Perform a technical peer review of different protocol approaches, first to develop interoperability among computer models and manned simulations and later to integrate computer models and manned simulators with instrumented tests. The first review would include the DARPA-funded ALSP, the TriService/DARPA-sponsored development of DIS protocols for linking distributed manned simulators, Data_Bus, and DICE. The second would include the Army-developed MILES II and other instrumentation used in separate service test and training ranges.

3) Review several candidates and determine the potential for establishing service-wide consensus on a working reference model of the battlefield or "Battlefield Description Language" as the "problem space" which could be related to a reference model of "solution space" outlining the performance attributes of M&S elements and their architectural relationships within the overall infrastructure. The reference model will address such parameters as scale of battle, variable resolution, time management, information flow, network control and bandwidth, and user interactions.

4) Prepare an "Interoperability Roadmap" and a generic strategy which integrates needs and priorities for interoperability within and among three classes and five functional areas (Education, Training and Military Operations, Research and Development, Test and Evaluation, Analysis, and Production and Logistics)

5) Plan and script a short course on benefits and implementation of M&S interoperability to educate DoD managers and M&S users about advantages and opportunities for incorporating more interoperability potential into current developments

APPENDIX B

METHODOLOGY ASSESSMENT

Most of this paper deals with models, simulations, and related technology (e.g., that permitting increased interoperability and distributed war gaming). This appendix is more concerned with the *content* and *design* of models and simulations, and the methodologies by which they are applied to DoD problems. This appendix considers (a) enriching the knowledge base from which models and simulations are built, (b) improving concepts and methods for designing and adapting models to deal with multiple levels of resolution (e.g., through hierarchies of models), (c) improving the manner in which military models deal with factors that have traditionally been excluded or poorly treated (e.g., behavioral factors), (d) verification, validation, and accreditation (VV&A), and, finally, (e) the efficient communication of information within the community.

B.1 BASIC FOUNDATIONS

Despite past accomplishments, it is important to further strengthen the foundations on which combat models and simulations are based, especially with respect to higher level processes, including joint operations. In particular, there is need for texts, new-research journals, review journals, in-depth scientific conferences, and a scientific style of open discussion and information exchange. These should not be thought of as "nice to haves," but rather as basic requirements in a long-term strategy.

Fortunately, we are not starting from scratch: the potential union of relevant existing knowledge is substantial. If we combine the knowledge reflected in military-technical studies, history, doctrine, and the lore and practices of operational organizations, then there is a great deal of knowledge. However, we are far from having achieved such a union of knowledge. Instead, there are distinct groups with relatively little contact with one another and no unifying framework. This is true both vertically and horizontally (i.e., those studying tactical phenomena often know little about operational-level phenomena and vice versa, and those studying ground forces often know little about air force or naval operations, and vice versa). Further, there is at least one gaping hole in our knowledge, which is how best to address the massive uncertainties that characterize a great deal of military analysis, especially above the weapon system level.

The vision is to develop a disciplinary structure that includes an appropriate mix of hard and soft knowledge and methods. The vision includes an emphasis on both empiricism and theory. These go together, especially when the empirical data is necessarily incomplete and for circumstances different from those encountered on the battlefield, and is best understood and exploited within the framework of theories.

It is striking that current work is often organized around models and simulations rather than the phenomena and operations they seek to represent. Part of the long-term DoD plan should be to change this focus and it is appropriate that the Defense M&S Initiative play a significant nurturing role here in cooperation with the Services, the Joint Staff, DARPA, and other defense agencies. Realistically, we should expect that it will take a decade to develop the necessary infrastructure (e.g., a comprehensive set of first-rate texts and forums for in-depth scientific exchange cutting across organizational boundaries).

Priorities for work should include (a) establishing relevant journals, (b) establishing a coordinated set of continuing scientific conferences for in-depth discussion and peer review, and (c) establishing courses in model design. Preliminary plans for such activities are now being developed.

B.2 VARIABLE AND CROSS-RESOLUTION MODELING

Recent research has highlighted the fact that all classes of users need combat models allowing them to move across levels of resolution. Policy analysts, for example, must be able to assess the reasonableness of their aggregated models by considering how they relate to higher-resolution depictions of combat (and by using such depictions to calibrate parameters). At the other end of the spectrum, users of high-resolution models representing, for example, individual weapons and firings, need lower resolution models to provide context (e.g., objectives, criteria, and interrelationships). As a final example, real-world military commanders (on the battlefield or in exercises) need to move back and forth between broad views of their domain and detailed views of critical portions. That is, they must "zoom in and zoom out" to do their job. They also need decision aids (a particular class of models) that operate at a variety of resolutions.

Surprisingly, this widespread need for cross-resolution operations has not typically been recognized in the past, especially when models have been designed. Instead, workers have developed ad hoc methods for connecting models of different resolution as needed, creating "families of models" by linking models of different resolutions. Unfortunately, models developed by different people with different perspectives and concepts have often led to a great deal of tedious and expensive work, inconsistencies, undocumented assumptions, and dubious analysis.

Quite recently, a workshop was convened with representatives from a large number of Federally Funded Research and Development Centers (FFRDCs), national laboratories, and government offices. Participants shared conceptions of the variable-resolution challenge and identified action items to be pursued in both research and conferences. The Defense M&S Initiative will need to encourage and assist this process, because it has major implications for model interoperability and reusability. Some of the issues involve theory (general modeling theory and theories of combat). Other issues involve the need to develop improved software tools and more comprehensive modeling environments to facilitate designing and adapting models with variable resolution. Such developments are typically too expensive for organizations to undertake on their own, and too expensive for sponsors of a particular project. Coordinated planning and funding may be desirable, with an emphasis on innovation, exposure, and subsequent dissemination of methods that work.

B.3 VERIFICATION, VALIDATION, AND ACCREDITATION (VV&A)

B.3.1 Definitions[3]

These terms are, regrettably, used in very different ways in different technical communities. Here we adopt the following definitions:

Verification. *Verification is the process of determining that a model implementation accurately represents the developer's conceptual description and specifications.*

Verification is a matter of degree for complex models because it is impossible in practice to test the model over the entire range of variable values. Thus, a model may be well verified within a particular "scenario space," but not well verified otherwise.

Verification consists of two basic parts. Logical and mathematical verification ensures that the basic equations, algorithms, etc., are as intended by the designer and do not include logical or mathematical errors such as divisions by zero, incompletely specified logic, or nonsense results when certain variables take extreme or unusual values. Code verification ensures that these representations have been correctly implemented in the

[3]The following discussion builds heavily on material developed as part of a special study for the Military Operations Research Society (see Phalanx, Vol. 24, No. 2, 1991). The definitions are taken from the study except for the bracketed additions, which will be recommended to the next MORS meeting on VV&A issues, scheduled for the spring of 1992.

computer program, which includes verifying that computations will not be erroneous by virtue of inappropriate numerical techniques or other implementation decisions.

Validation. *Validation is the process of determining (a) the [manner and] degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model [and (b) the confidence that should be placed on this assessment].*

To illustrate the reasons for this complex definition, note that some models can be expected to predict all aspects of certain real-world phenomena with accuracy and precision; some can be expected to predict all or some aspects accurately, but with substantial (and predicted) error ranges; and some models can be expected to represent all or some aspects well enough to have explanatory value, perhaps substantial explanatory value, but can not be expected to make accurate predictions. Further, some models can be accurately predictive only after the fact, because it is only after the fact that one knows values of key input parameters (e.g., the visibility at H-Hour or the tactics used by the antagonists). And, as a final example, some models may be judged to be predictive, accurate, and precise, but only if certain underlying concepts are correct, which may be uncertain. In using models to evaluate the effectiveness of future weapons, for example, one may have great faith in the models' predictiveness if and only if the antagonists apply particular tactics and find themselves fighting in certain kinds of contexts. Or, to use another example, a knowledge-based model specifying command and control decisions may be known to represent very well the decisions of current senior officers participating in war games (a type of validation), but that model may prove to be inaccurate with respect to predicting the decisions of a given commander in a real-world version of the same scenario.

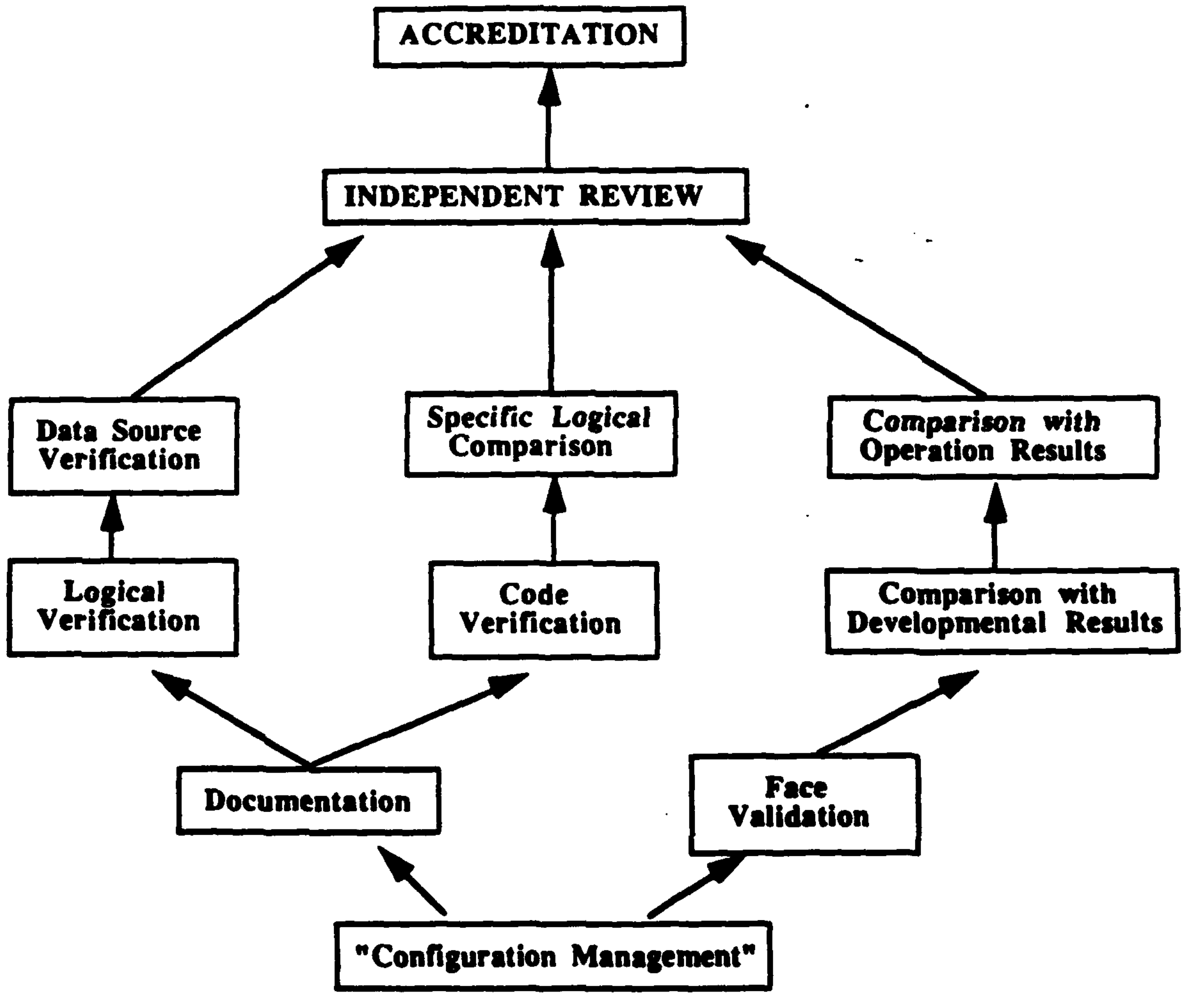
Accreditation (often used synonymously with certification). *Accreditation is an official determination that a model is acceptable for a specific purpose.*

Accreditation is a decision that a given level and character of verification and validation are sufficient to justify using a model in a particular application. Although it would be convenient if models could be accredited for broad classes of applications, the reality is that, even within a given class of applications (e.g., weapon system comparisons), there may be instances in which a model will be adequate and instances in which it will not. Which situation applies depends on the precise details of the comparison, including numerical details and the sensitivity of final results to errors in model performance. It is also the case that some models that might be thought inappropriate to a particular application can be effectively used if merely they are manipulated cleverly with the benefit of side calculations.

<u>Data.</u> The VV&A process is usually said to involve models but in fact it must also consider the data the models will use as inputs. Accreditation of an application takes into account not only the baseline data base but also the planned use of parametric variations to reflect uncertainty and alternatives. The dependence of results on data, which is typically uncertain, and the importance of sensitivity analysis are among the important reasons for emphasizing that both validation and accreditation must be in the context of an application.

B.3.2 The Combined Processes

The following figure shows one depiction of how VV&A is accomplished over time. It is to be emphasized that the various processes take place in parallel over long periods of time, with considerable iteration to reflect model adaptations and the need to consider suitability for new applications (or even new cases within the same class of applications). Thus, all of the judgments about VV&A may be revisited many times over a model's lifetime. Because of this fact and the many subtleties associated with the individual processes, some organizations prefer to speak in terms of having *VV&A regimes*, rather than using language that might suggest one-time decisions on VV&A.



B.3.3 Research Needed on VV&A Issues

Continued research and community-wide integration efforts are needed to encourage continued convergence on definitions and interpretations. Currently, there are major discrepancies across organizations in the manner in which they seek to achieve one or another concept of VV&A. An important role for the Defense M&S Initiative may be to provide concrete recommendations on common definitions (as in the above) and, importantly, suggestions on how to establish effective VV&A regimes. It may also be able to help coordinate or support the effective use of specialized model testing teams, which could, upon request, visit an organization and conduct systematic independent testing in a manner unlikely to occur within the organization itself.

A major investment area is development and dissemination of appropriate tools for modeling and analysis environments. Some software tools, for example, greatly improve the effectiveness and efficiency of model documentation, which is critical for VV&A. Other tools facilitate visual testing of many aspects of model structure and performance. It is unlikely that the needed tools will become available as the natural result of commercial developments in the private sector. Further, they are too expensive to be developed by the various organizations separately.

Further research is also needed on how best to proceed with VV&A activities when the models in question do not lend themselves well to classical validation efforts based on well-controlled experiments. One example involves decision models dealing with, for example, the commitment of reserves or the allocation and apportionment of sorties. How should such models be "validated?" The answer, presumably, is that they can be validated in only a very conditional sense such as: "This decision model describes the decisionmaking behavior that experts would expect to see for an officer attempting to follow Soviet doctrine. Confidence that real-world behavior would follow this model is only moderate, since commanders vary in their skill, adherence to doctrine, willingness to take risks, and knowledge at the time of decision." Another model might be less realistic but very important as a bounding case. One might say about it, after a validation exercise, "This model describes optimal decisionmaking by an idealized commander with perfect knowledge of...."

B.4 EXCLUDED AND POORLY TREATED FACTORS

In addition to the challenge of improving the quality of models and simulations in areas in which there has already been substantial work, there exists the challenge of treating a wide range of factors that are known to be important in real-world conflict, but which are excluded from most analysis, or treated poorly by one measure or another. These fall into several classes, notably: (a) decisionmaking, (b) other human-performance models in individual engagements and operations, (c) other soft factors in combat models, (d) environmental factors, (e) physical-mathematical factors, and (f) the treatment of uncertainty.

<u>Decisionmaking under uncertainty of military commanders at all echelons.</u> Often, combat models have no decision models, but instead rely upon scripts of decisions provided as inputs, in which case the decisions are nonadaptive. There now exist a variety of proven techniques for improving on this situation, which draw on artificial intelligence, mathematical programming, and simpler operations research methods. Other, more

advanced techniques using knowledge-based and game-theoretic models are in development. There has been little propagation of these techniques, however, beyond the groups that originally developed and applied them. An important near-term goal of the Defense M&S Initiative should be to encourage further work in this area and, importantly, create an environment in which the methods and knowledge bases (e.g., situationally dependent decision rules) can be transferred.

Other human factors. There are many other poorly treated human factors, including: weapon-system effectiveness when limited by human performance under stress (e.g., bomb-delivery effectiveness amidst intense air defenses rather than from stand-off ranges); force effectiveness as a function of deprivation (sleep, food, etc.); and suppression effectiveness of artillery and bombing, going beyond "physical" effects. A special case of this involves cultural and other country-specific factors. In addition to effects on nominal military doctrine, significance to force effectiveness of cultural attitudes, education, and training. Here one thinks of the significance to combat effectiveness of the quality of the noncommissioned officers and officers, of the existence or nonexistence of group loyalties, emotional stakes such as homeland defense, and other intangibles that greatly affect ability to withstand attack or to prosecute attack under adverse circumstances.

Of first-order importance in this category is the factor of readiness. It is common knowledge that real-world effectiveness in combat varies drastically as a function of the troops' prior levels of expertise, time since prior expertise, recent training time, quality and level of training, and the circumstances in which they are fighting. However, models seldom reflect these factors explicitly, except in assumptions about when reserve units will be deployed and committed. Even more than in the past, it is essential that DoD models be more realistic in these respects, because they can be critical in assessing what is feasible in a variety of contingencies.

Environmental factors. Although some high-resolution models exist at the weapon-system level to deal with environmental issues such as the implications of fog, rain, electromagnetic interference, and complex terrains, higher level models often fail to treat these issues. They are often not even parameterized appropriately for sensitivity analysis. Instead, battles are assumed to occur under average conditions. Much can be accomplished to improve this situation.

Physical-mathematical factors. Some of the current problems in DoD M&S involve very subtle and complex phenomena that can be described well only with sophisticated mathematical theories in which there has been very little investment. Two problems worthy of special attention include establishing how to properly reflect (a) the higher level (aggregated) consequences of low-level stochastic effects, and (b) the higher level (aggregated) consequences of low-level "configuration" effects. Examples of the former include representing the fact that not all battles characterized by the same macroscopic factors (force ratios, terrain, etc.) will have the same outcome, and that battlefield decisions and subsequent events will be strongly correlated (e.g., if one commander is luckier than others in achieving his mission, exploitation will follow his lead; operations will not follow expected-value logic). Examples of the latter include attempting to reflect the consequences of spatially structured operations on consequences at low levels of resolution for such disparate phenomena as concentration and counterconcentration of ground forces, naval operations in battle groups, and penetration of aircraft through SAM belts.

Treatment of uncertainty. An exceptionally difficult problem of particular importance in the post-cold-war era is how to conduct defense planning under massive uncertainty. No less difficult is how to provide decision aids for commanders that help them cope realistically with massive battlefield uncertainties. It is common for models, simulations, and analyses to be constructed as though the "best estimate" case is a good baseline, with only a modicum of sensitivity analysis necessary. This is one reason for the gulf that often exists between "operators" and modelers, whether the "operators" be generals or defense planners. To remedy this situation, a high priority should be placed on development of methods for multi-scenario analysis, methods that go far beyond standard sensitivity analysis. This will depend heavily on computer power and visualization techniques.

B.5 INFORMATION SHARING

The modeling and simulation community must promote the collection and flow of relevant information. This will allow better interchange throughout this widely dispersed community, thereby enhancing access to information. Improved communications will also reduce redundancy, improve interoperability and consistency of models and simulations, improve cooperation between functional communities, and quicken access to information. These improvements are factors in enhancing the efficiency and quality within the modeling and simulation community. An information service that cuts across the different modeling and simulation communities and provides timely information to a broad range of users will also contribute to the overall improvements within the modeling and simulation community. Nevertheless, information services alone will not solve the problems within the modeling and simulation community.

The approach used to enhance communication and access to information contains several parts. First, the modeling and simulation community must establish communication networks. Communication in computer and information systems takes the form of electronic mail and bulletin boards and these communication systems provide simple access to modeling and simulation users irrespective of geographic location. Electronic mail and bulletin boards provide rapid communications and a means to discuss special topics or collect functional and technical groups into communication forums.

Next, the modeling and simulation community must have access to information sources. Primarily, the community must have access to directories that describe models, simulations, data, activities, organization, and many other types of information. The utility of these directories depends on their content and the search and access tools provided to the users. Users must be able to identify and locate source of information quickly and easily.

After the information is identified and located, the community must have access to the original source of the data whenever possible. An information system can provide access to other systems and sources of data by functioning as a gateway to the rest of the modeling and simulation community. A gateway system allows users to access many different systems around the world quickly and easily, thereby reducing the need to keep separate copies of large data files on several machines and allowing the owners of data sets to easily grant access to the community.

Finally, to facilitate interoperability and provide the most useful information possible, the information system must work to integrate different sources and owners of data so that a common means of communicating and sharing information can be established. The information system will not replace the existing data collection organization; instead, it will augment these organizations by allowing users to easily locate and identify useful data and data sources.

APPENDIX C

TECHNOLOGY ASSESSMENT

Eight key technology areas provide the foundation for modeling and simulation: data base technologies, environmental representation, networking, software engineering, behavioral representation, instrumentation, graphics, and computer hardware.

A multi-pronged assessment was performed within each of these areas recognizing that these technologies have much broader applicability than just modeling and simulation. Initially, assessment efforts were filtered by identifying specific areas of relevance to modeling and simulation. For the areas of relevance, trend analyses were performed from a technology perspective. Subsequently, potential initiatives were defined for each technology area. These initiatives address issues within such categories as architecture/methodology, policy, standards, and specific technology thrusts. The following section briefly outlines these analyses of technology trends for each of the eight technology areas of interest.

Finally, a summary of the common trends and needs across these eight areas is given. To help focus the efforts of Defense M&S Initiative, the technology areas have also been evaluated with respect to the availability of resources from other organizations (i.e., commercial, other DoD Agencies, Services, Labs) to support them and their proposed initiatives.

C.1 TECHNOLOGY ASSESSMENTS

C.1.1 Data Base Technologies

Table C-1. Data Base Technologies Assessments

Areas of Relevance	Trends	Initiatives
• Memories • Secondary and archival storage • Data base machines • Data models • User interfaces • Security • Distributed data management • Open systems	• Larger memory chips, faster processing • Higher volume, faster access to secondary and archival storage • Forms to graphical user interface • Relational model to object oriented model • System high security to multi-level security • Homogeneous distributed data management to heterogeneous and federated • Improved standards and open systems capabilities	• Develop capability to provide timely and cost effective access to, acquisition of, and validation of data for setting up simulation models • Distributed data management to support distributed simulation and simulation sharing – Interoperability – Data integrity and consistency • Product assessment of DBMS products – Information on applicability of COTS products – Information on technology gaps – Develop advanced data representation techniques – Doctrine – Human behaviors • Develop advanced data representation techniques – Spatial/temporal data – Doctrine – Human behaviors – Imprecise/fuzzy data

The nine fundamental technology areas identified in Table C-1 will drive the advancement of data base technologies in support of modeling and simulation. Current developments in the area of database technology are largely driven by the demands of the commercial sector. Data base management systems (DBMS) products of the future will provide more memory, faster processing capabilities, higher volume, and faster access to secondary and archival storage. Historically, user interfaces have been limited to command line and forms entry. The current trend is to provide graphical interfaces with advanced navigation tools. Current trends are moving from relational models, system high security, and homogeneous distributed data systems towards the incorporation of object-oriented structures, multi-level security, and the management of heterogeneously distributed data bases. Improvements in standards and open systems are expected but not to the degree needed by the modeling and simulation community.

The modeling and simulation community has a high priority need for support in locating, accessing, acquiring, and aggregating data to be used as input to models as well as information about models themselves. An initiative is needed to develop an infrastructure that will supply the management, authority, and funding to ensure the design, development, service, and maintenance for directories, dictionaries, encyclopedias, and repository facilities across the modeling and simulation community. These facilities will reduce costs by providing capabilities to locate and reuse existing data. It will also reduce the likelihood of inconsistent modeling results and will support data base VV&A efforts.

To use data in real time within a network of multiple models, the modeling and simulation community needs to address the interoperability/sharing of data across distributed and diverse modeling and simulation applications and products. A second initiative would investigate the use of distributed data bases to provide data reliability, availability, integrity, improved performance, and consistency across distributed simulations, and the proper separation of data at different classification levels.

Currently, there appears to be no DoD organization responsible for assessing data base management systems and other software products. The modeling and simulation community would benefit with respect to cost, interoperability, and perhaps even technology development if an organization that fulfilled a "consumer union" role was formed which assessed existing products based on the requirements of the modeling and simulation community.

This organization would help develop advanced data representation techniques, evaluate commercial developments and R&D efforts, and identify technology gaps. Known deficiencies include spatial/temporal data such as terrain and environmental data, data expressing military doctrine and force behaviors, and imprecise/fuzzy data.

C.1.2 Environmental Representation

Table C-2. Environmental Representation Assessment

Areas of Relevance	Trends	Initiatives
• Processing power • Data handling • Remote sensing technology • Internetworking • Software environments	• Current – Integrated environmental modeling, rendering • Near term – New real time, user friendly, dynamic environmental models • Longer term – Global hierarchies of interoperable environmental models	• Develop integrated environmental modeling and rendering capabilities for a central data repository – Standards for -- Lexicons and definitions -- Automated feature extraction -- Environmental data base transport – Environmental data base repository • Develop near real-time, user-friendly, dynamic models – Identify environmental representation requirements – Develop environmental representation standards – Develop standard environmental process models – Develop algorithms, data structures for real-time representation and modeling • Develop a global hierarchy of interoperable environmental models – Develop intelligent environmental simulation managers – Analyze distributed environmental models/architectures – Synchronize environmental models

Requirements to model environmental effects continue to grow across the modeling and simulation community as the effectiveness of our advanced weapon systems is closely linked to the environmental state of the battlefield. Our ability to meet these evolving requirements is related to future advancements in computer processing power, data handling, remote sensing technologies, networking in support of distributed simulation, and the development of software environments.

Current technology will support integrated environmental modeling and rendering in the near term, while allowing rapid extension to near real-time, user-friendly, dynamic environmental models in the next four to nine years. Early in the next decade, global hierarchies of interoperable environmental models will be possible. While these outcomes are achievable, it is by no means clear that the community is yet sufficiently well-organized to effectively leverage anticipated technology developments.

Several near–term initiatives should be pursued to achieve a first generation capability for integrated environmental modeling and rendering. Three specific initiatives address the development of DoD-wide standards which include the development of standard lexicons and definitions, automated feature extraction from environmental databases for use by the simulation community, and environmental database transport standards. These standards initiatives will provide the framework to support an initiative to establish a central environmental data repository. The data repository will minimize duplication of effort, reduce associated costs, enhance data integrity, and maintain data currency.

A second set of potential initiatives is designed to achieve near real-time, user-friendly, dynamic environmental models. First, requirements for environmental models need to be identified across the modeling and simulation community. These requirements should then be used to develop a single, scalable common representation for environmental data. Standard environmental process models should then be developed for use across simulations to reduce developmental cost and enhance interoperability and analytical consistency. Finally, there is a need to develop algorithms and data structures for real-time environmental representation and modeling.

The final set of potential initiatives is aimed at the long-term objective of developing a global hierarchy of interoperable environmental models. It is expected that there will be a need to develop intelligent environmental simulation managers in order to ensure realistic dynamic environmental effects. It is also important that longer-term focused technology development be initiated in the areas of analyzing distributed environmental models/architectures and the synchronization of environmental models.

C.1.3 Networking

Table C-3. Networking Assessment

Areas of Relevance	Trends	Initiatives
• Interoperability • Security • Multi-casting • Network management	• Many separate networks, at single security levels to shared, integrated, multimedia networks at multiple security levels • Increases in network performance – Speed – Capacity • Declining costs	• Multi-level security (e.g., policy, applications) • Standards to support – Multi-casting – Real-time service • Network and systems management of multipurpose, single network

Key networking technology areas of concern center on how the current and future multiple networks can be made interoperable, accept implementation of proper security procedures (DoD and industry proprietary), incorporate multiple media and distributed participants via multicasting, and effectively manage diverse and multiple priority level sets of information packets.

Networked communications are central to the goals of improving communications within the modeling and simulation community, and the development of interoperable distributed simulations. Advances in networking technologies are at a crossroads that will move the DoD networking architecture from one that can be characterized as many separate networks at single security levels to a future architecture of a shared integrated multimedia network at multiple levels of security. This will be made possible as a result of increases in network performance (e.g., speed and capacity), declining costs, and advances in technology.

The exploration of networking technology in the DoD should be predicated on the utilization of an abundance of commercial networking products and services to the maximum extent possible. Areas where the commercial sector is expected to fall short, such as security policy for distributed secure simulation environments, should be the primary focus for defense investments. Other key issues include the development of standards to support multicasting and real-time service to meet training simulation requirements, and network and systems management of a single network designed to provide a wide range of services as opposed to multiple unique networks.

C.1.4 Software Engineering

Table C-4. Software Engineering Assessment

Areas of Relevance	Trends	Initiatives
• Structure • Formalization • Domain definition	• Stand alone to distributed/interoperable systems • Enhanced reuse/extensibility • Better defined architectures and standards (e.g., enhanced capability maturity)	• Language specification • Enhanced tools and practices – Improved developmental environments (e.g., analyst workstation) – Quality assessment metrics and procedures – Re-engineering/re-use technologies

Software engineering is recognized as one of the primary drivers of the modeling and simulation community. It is often found on the critical path of success as a function of time and/or cost constraints. In general, the practice of software engineering in the modeling and simulation community will continue to improve in the future at a moderate rate as compared to the more immediate affects that may be realized by such technologies as hardware, graphics, and network communications.

Many of the tools and practices associated with software engineering can be characterized as emerging technologies that are being developed for the software engineering community in general. From the perspective of modeling and simulation, the software engineering areas of relevance focus on structure, formalization, and domain definition. Emphasis has been placed on the front end of the software development process with the development of long-term requirements and specifications.

The design of models and simulations will move from stand-alone systems to distributed, interoperable systems. Emphasis will be placed on the reuse and extensibility of software to meet what is perceived as a very dynamic set of requirements for the modeling and simulation community. The further development of well-defined architectures and standards, through the capability maturity model and distributed, interoperable systems, has been and remains paramount to the success of the software engineering community.

Controversy continues about the desirability of mandating the use of one (or more) computer language by the modeling and simulation community. To establish the foundation for policy in this area, an initiative is needed to clarify the relative capabilities and limitations of candidate languages (e.g., Ada vs. C++). In addition, potential initiatives in software engineering should focus on the development and evaluation of numerous emerging tools and practices to ascertain their applicability and appropriateness to the specific requirements of the defense modeling and simulation community. Specific initiatives in software engineering include development of software engineering environments, including an analyst work station; development of quality assessment metrics and procedures for modeling and simulation; exploitation of re-engineering technology; and the evaluation of existing software repositories for re-use by the modeling and simulation community.

C.1.5 Behavioral Representation

Table C-5. Behavioral Representation Assessment

Areas of Relevance	Trends	Initiatives
• Cognitive processes • Soft factors; e.g., – Fear – Fatigue – Cultural bias • Command decision-making • Planning, tactics, doctrine	• Improved formal methods, tools • Enhanced representation of automated forces (manifesting human judgment) • Improved individual training simulations • Emergence of variable resolution simulations with explanation capabilities	• Develop scientifically sound validation criteria for behavioral representations • Explore variable resolution and interoperability between behavioral models • Develop a repository of relevant knowledge bases and representation techniques for – Tactics – Doctrine – Soft factors – Decision-making

Models and simulations need to represent behavior in a variety of ways. Key aspects to be represented include cognitive processes, soft factors (e.g., fear, fatigue, cultural bias), command decision-making, and planning, tactics, and doctrine.

There have been significant advances in representing behavior over the past decade. This has come about through improved formal methods and tools (e.g., paradigms for knowledge acquisition and engineering; expert system shells/languages). In addition, the use of knowledge-based, multi-agent and adversarial behaviors, and standardized representations are promoting the use of automated forces that can model decision-making and human judgment. This will lead to improved training environments that more accurately portray the battlefield and can provide individualized feedback during training. Methods of identifying and validating correct behavior are providing more realistic, credible models. For example, technology is giving rise to knowledge-based simulations with multiple levels of resolution as well as explanations of the output of the model for the user.

However, several initiatives are required to take full advantage of these trends. Scientifically sound validation criteria for behavioral representations in modeling and simulation have not been adequately developed and variable resolution and interoperability between behavioral models are issues that need further development. By extending some of the symbolic processing techniques developed within the artificial intelligence community, advancements are possible in the representation of behaviors.

Efforts should be made to apply validation methodologies to this arena in order to increase the credibility of behavioral models. A repository of relevant knowledge bases and representation techniques for tactics, doctrine, soft factors and decision-making should be developed. This can be particularly useful for the automating of opposing forces and in training situations. This would include the goal of finding common semantics and descriptions of behaviors of diverse models which promote attaining interoperability and improved validation procedures.

C.1.6 Instrumentation

Table C-6. Instrumentation Assessment

Areas of Relevance	Trends	Initiatives
• Linking M&S to training/testing • Source of data for VV&A • Technical compatibility of collection systems • Time, space, position, information (TSPI) systems limitation	• Enhanced mobility and coverage via GPS • Extended range and participant numbers by satellite and packet communications • Faster data reduction using digital systems	• Develop standards – TSPI – Endgame – Diagnostic – Field and M&S augmentation • Release of joint training/testing data • Enhancement instrumentation technology – Communications – Sensors – Processors

Instrumentation is relevant to the modeling and simulation community in two major areas. First, it provides the basis for linking modeling and simulation and geographically distributed combat units participating in training/testing events. Second, it provides a source of data from field events that can be used for the verification, validation, and accreditation (VV&A) of modeling and simulation.

Currently, instrumentation systems are characterized by several significant shortfalls. Most such systems are incompatible (e.g., with respect to data formats, frequency, baud rates, update rates, accuracy) and there is a dearth of standards in the field. In addition, Time, Space, Position Information (TSPI) systems are limited by update rates, line of sight, and number of participants.

Existing technology trends promise to enhance the quality of TSPI systems appreciably. The introduction of Global Positioning System (GPS) receivers in player packages will tend to enhance mobility and coverage. Satellite communications and packet-switched communications will mitigate limitations on line of sight and numbers of participants. Finally, developments in high technology digital recording and playback systems have the potential to expedite the reduction of data.

However, a number of initiatives are needed to ameliorate residual issues. First, standards are needed in several key areas. To promote interoperability among Service instrumentation systems, community-accepted data formats and protocols are needed for TSPI, endgame, and diagnostic systems. In addition, standards are needed to facilitate the real-time augmentation of field events with modeling and simulation. Second, joint training/test data are a valuable potential resource for enhancing the quality of modeling and simulation. However, it will require policy initiatives to stimulate the release of that data. Finally, a technology push is required to enhance instrumentation further. This would include concerted efforts to enhance communications (e.g., to provide improved millisecond response times, at megabit/sec data rates, for tens of thousands of participants), improve sensor systems (e.g., use of infrared to mitigate obscurants), and expand computational power (e.g., use of VHSIC/MMIC technology to provide smaller more powerful processors).

C.1.7 Graphics

Table C-7. Graphics Assessments

Areas of Relevance	Trends	Initiatives
• Displays • Man-machine interactions • Abstractions	• Lowering cost and improved fidelity in mass market areas • Visual realism to virtual reality • Low-end standards are effective, high-end standards remain cumbersome/restrictive	• Better 3-D displays via developments in rendering engines, display buffers, transfer mechanism • Expand ways humans interact with graphics • Develop a military simulation tool kit • Improve graphic rendering algorithms used on parallel computers • Support development of graphics standards

The exploitation of human computer interface technology offers a significant improvement in productivity for the modeling and simulation community. This graphics assessment focuses on the various mechanisms for display, the man-machine interactions with the display and the different means of how abstractions can be incorporated within the displays.

The overall trend in graphics is improved cost performance and fidelity. Several commercial activities, especially in games, have been very dynamic and offer significantly increasing capabilities at lower costs. New paradigms for human-computer interaction, including changes from visual realism to virtual reality, are emerging. Graphical standards for high fidelity dynamic scene descriptions have been found to be cumbersome and restrictive. Conversely, standards for low-end (2-D, low performance 3-D, graphical user interfaces) are considered effective.

There are several areas where initiatives could help further expand DoD modeling and simulation developments. Better 3-D displays are needed to support more realistic training and to help designers understand the inter-relationships among parts (especially moving parts) within complex systems. Work is needed in the development of efficient image transfers and the associated geometry "engines" that create those images. This includes rendering engines, display buffers, and transfer mechanisms. Another area is to expand the ways humans interact with the graphics (e.g., man/machine interfaces, sensors, pointing, and portability).

A short-term initiative should be considered to develop a military simulation toolkit. This toolkit should be highly portable and feature primitives for displaying military symbology and map information. Improvements are needed in algorithms related to such issues as the modeling and display of the human body and parallel implementation of graphics-rendering algorithms. A long-term initiative is needed to identify several levels of graphics standards. As part of this effort, appropriate levels of abstraction should be identified for the various classes of models and simulations.

C.1.8 Computer Hardware

Table C-8. Hardware Assessment

Areas of Relevance	Trends	Initiatives
• Supercomputers • Mainframes • Workstations • Microcomputers	• Increasing – Functionality – Computat-ional speed – Memory capacity • Decreasing costs	• Real-time applications employing geographically distributed resources • Parallel algorithm development for massively parallel machine • Interoperability of COTS products

In the last decade, advances in hardware technology have significantly influenced the modeling and simulation community. Continuous improvements with respect to hardware performance and memory capacity have resulted in the fielding of supercomputers and mainframes that are capable of very high computational speeds (e.g., billions of floating point operations per second), and the proliferation of powerful workstations and minicomputers capable of running larger simulations. In particular, the promise posed by new workstations, with their outstanding raw performance characteristics at remarkably low cost, suggest that they may be of particular interest to the modeling and simulation community. These trends are expected to continue in the future, providing the modeling and simulation community the ability to perform a variety of tasks across a broad set of applications.

In general, computer hardware will continue to increase in functionality, computational speed, and memory capacity while at the same time costs will decline. This is largely due to the significant interest on the part of the commercial sector.

Unless certain issues are directly addressed, the benefits of these hardware advances to the modeling and simulation community could be diluted or could disappear entirely. Real-time applications, particularly those that may be geographically distributed, may challenge the resources of computers beyond their capability. Real-time computer solutions require not only that the hardware provide a sufficient number of executable instructions to satisfy the application, but in addition, these instructions must be executed in a fixed period of time. This requirement, therefore, places a lower bound on the required performance of those systems used in such real-time applications.

Parallel algorithm development may be essential for some applications since the trend in supercomputer architectures will be towards those employing massive parallelism. Therefore a shift is needed in algorithms to highly parallel versions whenever the use of massively parallel supercomputers is required.

Interoperability is another concern which must be carefully considered, understood, and properly managed. The use of COTS hardware is just as important a principle as it is in software, which means that there will almost certainly be a requirement to connect equipment from different vendors. There is a clear need to develop the necessary standards that will facilitate the linking of disparate systems.

C.2 SUMMARY OF TRENDS AND NEEDS

In looking across the component technologies, several common trends and needs are clear. In the area of common trends it is apparent that revolutions are underway in these technologies which have the potential to improve dramatically our ability to develop and use modeling and simulation. In nearly every component technology these trends promise enhanced capabilities (e.g., faster, high capacity) at significantly reduced costs.

However, in order to exploit fully these technological advances, several common non-technology needs are apparent. First, architectural visions are required to guide modeling and simulation activities so the users can incorporate the most cost-effective advances at the most opportune time. Key areas where such guidance is needed include COTS products, levels of interoperability, support structure, and abstraction levels. Second, major methodology concepts need to be defined. These include such aspects as modeling and simulation product metrics and assessments; VV&A for software, hardware, and systems; and unit aggregation. Third, policy directives are needed to break down community barriers and enhance discipline among modeling and simulation practitioners. Identified initiatives are in the areas of language specification, network security, releasibility of joint training/exercise data, and promotion of rigor and structure in the development of modeling and simulation.

Consistent with these architecture, methodology, and policy needs, more effective efforts are needed to enhance the implementation of standards within all of the technology areas. Catalytic efforts are needed in the identification of lead organizations, which would monitor standard development activities, formulate and evaluate alternatives, and promote mutually reinforcing efforts. These standardization efforts should facilitate community sharing by establishing multiple, easily accessible repositories of knowledge and data which support all technology areas.

To identify technology areas to which the Defense M&S Initiative should consider allocating its resources, consideration has been given to the availability of resources from other organizations (i.e., commercial, other DoD organizations) to support them. Three broad categories have been identified that should help define the level of emphasis that DMSO should place on the technologies of interest:

1. There is no existing organization that would be expected to support the suggested initiatives for the modeling and simulation community.
2. Other organizations (primarily within DoD) are available that can allocate substantial resources, but their main interests are not directly concerned with overall modeling and simulation technology advancement.
3. Extensive commercial investments are anticipated that should general satisfy the needs of the modeling and simulation community.

Two technology areas, data base management and environmental representation, are perceived to fall within the first category. As such, they are critical candidates for support by the Defense M&S Initiative. Four technology areas are perceived to fall within the second category: instrumentation (which is also of primary interest to the test and evaluation community), networking (which is being extensively pursued by DARPA and DISA), software engineering (which is supported heavily by the acquisition community), and behavioral representation (which is being pursued by the Services' human factors laboratories). These activities are still important candidates for the Initiative's support to ensure that advances in these technologies are translated into appropriate benefits to the modeling and simulation community. Finally, graphics and computer hardware are perceived to fall within the third category due to heavy commercial investments. However, the Initiative should continue to monitor and influence these technologies, with very limited resource commitments, to satisfy the residual needs of the modeling and simulation community.