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MODELING AND SIMULATION: A DEPARTMENT OF DEFENSE CRITICAL TECHNOLOGY

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ABSTRACT

The Department of Defense has identified twenty technologies critical to ensuring the long-term qualitative superiority of United States weapon systems. Simulation and modeling technology, one of these twenty, was categorized as one which offered the most immediate advances in weapon systems capabilities. A linkage is drawn between twelve major long-term goals reflecting needed military capability and the twenty critical technologies. This paper focuses on simulation and modeling technology and the author's view of how Air Force needs impact this technology.

1 INTRODUCTION

Congress has required, through enactment of Public Law 101-189, that the Department of Defense (DoD) submit an annual plan for developing the technologies most critical to ensuring the long-term qualitative superiority of United States weapon systems. The most recent report (DoD 1990), dated 15 March 1990, listed twenty critical technologies, one of which was "Simulation and Modeling". Along with this list, the DoD developed an investment strategy and a strategic plan to support development of these technologies. This plan identifies twelve major long-term goals and provides a linkage between these goals and the critical technologies. These goals are identified in Table 1 and linkage between critical technologies and long-term goals are provided in Table 2.

Each of the twenty technologies were selected based on the following criteria, broken into three broad categories. To be considered critical, major improvements in one or more selection criteria were sought. The categories are:

Performance Criteria
- Enhancing performance of existing weapons systems
- Providing new military capabilities

Quality Design Criteria
- Contributing to availability, dependability, reliability
- Contributing to weapons systems affordability

Multiple Use Criteria
- Pervasiveness in major weapon systems
- Strengthening the industrial base

All technologies were prioritized into one of three groups. In the first priority group were the most pervasive technologies; the second group consisted of enabling technologies which offered the most immediate advances in weapon systems capabilities; while the third group was the emerging technologies whose applications are farthest in the future and most difficult to identify in detail at this time. Simulation and Modeling was placed in the second group with the enabling technologies. By grouping these technologies together, DoD can plan better for funding to support each type of technology. At the present time, a Critical Technologies Plan is being drawn up and a specific implementation plan will be developed for each technology.

2 DoD SIMULATION NEEDS

Historically the DoD has used simulation and modeling in many ways. These uses have spanned the full spectrum of available techniques: continuous, discrete, combined continuous-discrete, and Monte Carlo. Indications for the future are that this will continue, but the areas of application will increase. Though technically challenging, simulation and modeling offer an affordable alternative to extensively testing hardware, to training with actual systems, and to developing new battle tactics and force employment concepts. Just as importantly, simulation and modeling

Table 1: Major Long-Term Goals of the Investment Strategy

DETERRENCE

Goal 1. Weapon Systems that can locate, identify, track, and target strategically relocatable targets.
Goal 2. Worldwide, all-weather force projection capability to conduct limited warfare operations (including special operations forces and low intensity conflict) without the requirement for main operating bases, including a rapid deployment force that is logistically independent for 30 days.
Goal 3. Defense against ballistic missiles of all ranges through non-nuclear methods and in compliance with all existing treaties.

MILITARY SUPERIORITY

Goal 4. Affordable, on-demand launch and orbit transfer capabilities for space-deployed assets with robust, surviable command and control links.
Goal 5. Substantial antisubmarine warfare advantages the United States enjoyed until recent years.
Goal 6. Worldwide, instantaneous, secure, survivable, and robust command, control, communications, and intelligence (C3I) capabilities within 20 years, to include: (a) on-demand surveillance of selected geographical areas; (b) real-time information transfer to command and control authority; and (c) responsive, secure communications from decision makers for operational implementation.
Goal 7. Weapon systems and platforms that deny enemy targeting and allow penetration of enemy defenses by taking full advantage of signature management and electronic warfare.
Goal 8. Enhanced, affordable close combat and air defense systems to overmatch threat systems.
Goal 9. Affordable "brilliant weapons" which can autonomously acquire, classify, track, and destroy a broad spectrum of targets (hard fixed, hard mobile, communications nodes, etc.).

AFFORDABILITY

Goal 10. Operations and support resource requirements reduced by 50 percent without impairing combat capability.
Goal 11. Manpower requirements reduced for a given military capability by 10 percent or more by 2010.
Goal 12. Enhanced affordability, producibility, and availability of future weapons systems.

Table 2: Major Linkages Between Critical Technologies and Major Long-Term Goals for the S&T Program

Critical Technology	Goals* 1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1. Semiconductor Materials and Microelectronic Circuits	X	X	X	X	X	X	X	X	X	X	X	X
2. Software Producibily	X	X	X	X	X	X	X	X	X	X	X	X
3. Parallel Computer Architctures				X		X			X	X		
4. Machine Intelligence and Robotics				X				X	X	X	X	X
5. Simulation and Modeling		X				X		X		X	X	X
6. Photonic						X			X			X
7. Sensitive Radars	X		X		X	X		X	X			
8. Passive Sensors	X		X		X	X		X	X			
9. Signal Processing	X		X	X	X	X			X		X	
10. Signature Control	X		X		X		X					
11. Weapon System Environment	X	X	X		X			X	X			
12. Data Fusion	X		X	X	X	X				X	X	
13. Computational Fluid Dynamics					X	X			X			X
14. Air-Breathing Propulsion		X		X			X	X		X		X
15. Pulsed Power			X					X				X
16. Hypervelocity Projectiles			X					X	X			X
17. High Energy Density Materials			X	X				X		X	X	X
18. Composite Materials	X	X	X	X	X	X	X	X	X	X	X	X
19. Superconductivity			X		X	X				X		
20. Biotechnology Materials and Processes										X	X	X

* The numbers of these goals correspond with the goals in Table 1.

allow the DoD to examine many strategic and tactical options in a "near-laboratory" environment. This latter characteristic is especially critical when dealing with nuclear options or employments involving extremely large numbers of forces on a global scale. The following sections detail several major areas of application in which the DoD sees simulation and modeling playing a major role in the near future.

2.1 Future Weapon Systems

The acquisition of any major weapon system, such as an aircraft, tank, satellite, or ship, is a very expensive process. This acquisition involves years of time, billions of dollars in research, development, and acquisition costs, and considerable risk that the system will actually counter the threat when delivered. Any means that will shorten the lead time, decrease the cost, or lessen the risk is greatly needed. Simulation and modeling offer help in all three of these areas and, therefore, the DoD is looking much harder at these techniques, especially, in the era of declining budgets.

For some time it has been possible to simulate a weapon system, such as an aircraft, in its proposed environment. However, the demands for additional detail in that environment are increasing dramatically. Because of requirements to accelerate systems through the acquisition process, extensive amounts of "fly before you buy" testing are being eliminated. However, the need to evaluate the system still exists. Quite often, it is necessary to determine the best combination of subsystems to maximize system effectiveness. Subsystem operating ranges and capabilities must be defined. Human-machine interfaces must be evaluated. Interactions between several systems, such as a flight of aircraft, must also be optimized is some way.

In the past, much of this was done by a cycle of test-modify-test, but time and budget constraints have ruled out this option. Simulation and modeling can play a critical and cost effective role here doing just these things. The future requires simulations with much more detail at the subsystem level to allow this test-modify-test process to be simulated while actual hardware tests are conducted primarily at the subsystem level. This process also suggests that future simulation modelers will need to be more than just simulation experts; they will also need to understand aircraft subsystems and the integration of these subsystems into a composite whole.

2.2 Combat Analysis

With continuing pressure to decrease operating, support, and acquisition cost it is imperative that all existing forces be employed in an optimal manner. Since major hostile actions do not occur very often, it is very difficult to understand or quantify the effects of various strategic and tactical options. Simulation offers a chance to examine these options in a controlled environment and explore various strategic and tactical concepts. This is especially true when political or economic problems preclude evaluation of strategies and tactics involving joint service or international operations.

The use of simulation and modeling for combat analysis could be greatly expanded in several areas. One such area is to examine ways to increase force effectiveness and readiness in very large battlefield scenarios. This is currently being done, but a need exists to expand the amount of detail so that the impact of a small change in an aircraft, tank, or ship can be measured by its effect on the overall battle. For example, it may be desirable to know how an air campaign the size of Desert Storm would have been changed if AMRAAM air-to-air missiles were used instead of SPARROW missiles. Such a simulation should capture other details, such as interactions with AWACS, the electronic warfare environment, and important supportability issues.

Another key area where simulation and modeling can facilitate combat analysis is electronic warfare. Especially needed are simulations which model coordinated force-on-force scenarios. The goal of these modeling and simulation efforts is to prescribe coordination procedures for combined electronic countermeasures against enemy threats.

2.3 Training

Simulation has begun to play an ever-increasing role in the area of training military personnel. Once developed, a simulation can be a low-cost alternative to more conventional methods. The uses of simulation span the entire spectrum of training needs. Maintenance personnel, pilots, equipment operators, combat planners, and general officers all have benefitted from training provided via simulation.

Many types of wargames have been developed which contain an imbedded simulation. Typically, the purpose of a wargame is not to conduct combat analysis, evaluate hardware, or define a battle outcome, but to train the wargame's players in the decision processes involved in the game's scenario. Wargames have been conducted at many levels of combat, in many different scenarios, and have provided extensive training for participants. Challenges remain, however, to increase the flexibility, realism, and user-friendliness of these games.

2.4 Battle Management

Modern sensors, such as those carried on special aircraft and satellites, have deluged battle commanders with information to the point that they simply cannot sort out the significant from the trivial. To counter this problem the DoD is developing a wide variety of automated battle management aids and sophisticated command and control systems. The intent is to provide critical information to a commander in a timely manner.

Simulation and modeling are playing an increasingly important role by providing a means of testing various options before hardware is designed, purchased, and built. Since the information provided for battle management must ultimately be interpreted by a human, considerations of the human-machine interface must also be incorporated into the simulation. Perhaps the largest project in this area is the simulation Test Bed designed to evaluate and validate concepts for the Space Defense Initiative.

2.5 Manufacturing

Because of demands for increased system performance, military systems are constantly pushing the state-of-the-art of manufacturing technology. Simulation and modeling of metalworking processes, such as forming, casting, and welding, are currently on-going. The use of simulation permits process parameters to be defined without a trial and error effort on actual plant equipment. Simulation also allows the exploration of process alternatives during the design stage. The drive to push beyond state-of-the-art manufacturing technology by the DoD has contributed to this country's industrial base. However, many more applications of simulation to manufacturing remain to be developed.

2.6 Milestones

Table 3 shows major milestones established by the DoD (1990).

3 MAJOR TECHNICAL CHALLENGES

Despite the fact that simulation and modeling is a widely used analysis technique, it is still considered a critical technology. The reason for this is that many challenges remain to increase the usability of simulation and overcome some of the disadvantages previously mentioned. For example, in the area of model validity, a great deal of research is currently underway to find new validation methods. Especially critical is the validation of models of large, complex systems that are still in the planning or design stage. Such a validation effort has recently been under way to validate models of the SDI system.

Additional research is also underway on a variety of statistical analysis techniques often used with simulation. The output from large models is often characterized by large variance, which increases the confidence interval size for estimating system parameters. One way to compensate for this is to run additional replications of each experiment, a very costly cure for large models. Other, more cost-effective methods, such as variance reduction methods, are currently being researched. These methods require relatively little extra computational effort, but have shown great promise in reducing model variance.

Research is also underway to find new ways to apply experimental design theory to analyze simulation output. Of special interest is finding ways to optimize a system design through simulation experimentation. One promising method appears to be the use of response surface methodology. Other classical, non-linear search techniques from the field of optimization are also being tried. As the complexity of models grow, so does the challenge of making sense out of the increasing amount of output data available.

The growth of computational power throughout the computer world has increased the use of simulation. However, much effort is needed to learn how best to apply new computer technology. For example, parallel computing appears to offer potential for shortening the run times of large simulation models. Intuitively, it seems that running various parts of the model on different processors would shorten run times significantly. However, it is critical in simulation that certain events be synchronized chronologically, but its not clear how this might be done on a parallel computer having multiple processors.

Most recently, computer animation capability has been added to many of the commercial simulation packages. Animation has the potential to enhance understanding of simulation models by showing a non-modeler exactly what is happening within the simulation. In one sense, animation contributes to face validity since it makes the simulation process more understandable and believable. However, animation is not free. Even with a high quality commercial simulation package, adding a well-defined animation to an existing model can take just as long as developing

Table 3: Milestones--Simulation and Modeling

Technical Area	By 1995	By 2000	By 2005
Military simulation and modeling	Integration of battle-field simulation into a battle management test bed to have a test and evaluation approach for new planning and decision aids, pinpointing deficiencies in existing aids as the threat changes, and evaluating the effect of changes in our own doctrine, tactics, weapons, etc.	Application of knowledge-based techniques for design of complex systems including large software systems and battle management simulations Demonstration of C31 workstation Order-of-magnitude cost reduction for training and human factor design	Substantially improved battle mamagement decision aids, human factors design, and cost-reduction techniques
Industrial simulation and modeling	Modeling performance of hypothetical designs to help make trade-off decisions for optimal design	Diagnostics and prognostics by modeling alternative situations	Substantially improved cost effectiveness, planning, and design

the original model. Furthermore, whether intentional or not, it is possible to get the animation to show one thing while the underlying model is doing something else. Continued hardware and software development should aid immensely in making animation much more usable.

4 SUMMARY

Simulation and modeling technology offers great potential for addressing a wide variety of complex DoD problems. This technology has been applied successfully to every facet of the DoD including weapon design and acquisition, tactical and strategic operations, training, and maintenance. Simulation addresses a wide variety of technical problems by using continuous, discrete, and combined continuous discrete modeling techniques. In some cases, simulation solves problems that are unsolvable by any other means. A number of technological challenges remain, however, to overcome some of the disadvantages of the technique.

REFERENCES

Department of Defense, 1990. Critical Technologies Plan. Committees on Armed Services, United States Congress.

Schuppe, T.F., 1991. Simulation and Modeling. In: *Critical Technologies for National Defense*, ed. J.S. Przemieniecki, 229-240. Washington D.C.: American Institute of Aeronautics and Astronautics.

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