Report of the Defense Science Board Task Force on Simulation, Readiness and Prototyping

Impact of Advanced Distributed Simulation on Readiness, Training and Prototyping

January 1993

OFFICE OF THE UNDER SECRETARY OF DEFENSE FOR ACQUISITION
WASHINGTON, DC 20301-3140

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OFFICE OF THE SECRETARY OF DEFENSE
WASHINGTON. D C 20301-3140

DEFENSE SCIENCE
BOARD

19 JAN 1993

MEMORANDUM FOR DIRECTOR, DEFENSE RESEARCH AND ENGINEERING

SUBJECT: Final Report of the Defense Science Board Task on Simulation, Readiness and Prototyping

I am pleased to forward the attached DSB report entitled "Impact of Advanced Distributed Simulation (ADS) on Readiness, Training and Prototyping?

The Task Force has concluded that this technology, if adopted and exploited,

1) will make very substantial enhancements in training and readiness,

2) will dramatically improve the requirements/prototyping process and

3) can transform the current acquisition process from within.

Substantial ADS Technological capabilities are provided by the commercial sector and are available today. Relatively modest future DOD investment will be needed to realize full ADS potential.

These assertions are based on a judgement concerning confidence. The Task Force has found that the warfighting community has embraced ADS and is extending its utility. Through its power, the warfighters are applying distributed and multiple simulations methods to improve planning, training and mission rehearsal. The crux of the matter is that they have developed the confidence to use this new technology to prepare for those most serious of circumstances where human lives are at stake.

In contrast, the requirements/development community employs single and non-distributed simulation techniques which are less powerful and in which they have less confidence. As a result, the acquisition process is slowed with resulting cost increases and extended programs.

ADS technologies can provide the confidence-building needed for these acquisition transforming changes. The Task Force, through a set of five recommendations, crafted a short term experimental program to create the environment to enhance training and readiness and the means to allow the developer to work in this common environment with the warfighter. This environment is seen as the enabler to build the developer's confidence to speed his process and in so doing, save time and money.

You were briefed on the results of the Task Force in late September. In the interim between that briefing and the completion of the final report, there have been extensive working level interactions between the Task Force, the warfighters and the developers. One of the recommendations has been implemented. There is substantial interest and enthusiasm for the remaining initiatives outlined in the report.

Of the few "new" things the Department might undertake, this is one of the highest leveraged and least cost possibilities. I recommend this to you as a priority initiative.

John Foster Jr

John S. Foster, Jr.
Chairman

Attachment

OFFICE OF THE SECRETARY OF DEFENSE
WASHINGTON, D.C. 20301-3140

DEFENSE SCIENCE BOARD

Dr. John S Foster
Chairman, Defense Science Board
OUSD(A), Room 3D865, The Pentagon
Washington, DC 20301-3140

21 December 1992

Dear Dr. Foster:

We submit herewith a final report for the Task Force which addresses the "impact of Advanced Distributed Simulation (ADS) on Readiness, Training, and Prototyping". We believe that the Task Force has addressed fully the objectives of the Terms of Reference.

It is our belief that ADS technology can greatly improve training and readiness, will help expedite prototyping, and can transform the acquisition process from within. It is being adopted by the war-fighters but it can be exploited in a much larger context,

We have described an experimental approach to build the confidence needed to achieve these objectives in the shortest possible time. As required, the report also contains a specific prioritization for the maturing of ADS technology and filling voids.

This report is the result of the efforts of its DSB members, its consultants from industry and the extensive support of DDR&E, the T&E community, the Services, and the Joint Staff. It has been a pleasure and a privilege to have led such a talented and dedicated group.

Very truly yours,

Dr. Joseph V. Braddock
Co-Chairman

General Maxwell R. Thurman, USA (Ret.)
Co-Chairman

Executive Summary

This is the final report of the Defense Science Board Task Force on Simulation, Readiness and Prototyping. The report is a detailed, user friendly document designed for the uninitiated and the informed alike. The main body of the report consists of the unabridged briefing viewgraphs with explanatory facing text.

Attached to the main body of the report are three (3) appendices. Appendix A is the result of a very extensive evaluation by the Task Force panel on technology assessment evaluating current and projected technologies associated with Advanced Distributed Simulation (ADS). The broadening scope of applications for modeling and simulation in the Department of Defense is driving a widening range of technologies. The scope of applications for modeling and simulation include requirements definition and analysis, virtual prototyping, program planning, engineering design and manufacturing, test and evaluation, and training and readiness. The approach taken by the technology assessment panel was to develop a hierarchy of enabling technologies and to segregate them into two categories -- those which are primarily commercially driven and those which are primarily driven by DOD. Some enabling technology areas fall into a middle area in which both commercial industry and DOD are investing. The achievement of the following two objectives is of great importance to the DOD: (1) to correctly identify the key enabling technology areas which DOD must follow and invest in, and (2) to assess the maturity and to estimate the on-going investment activity for each technology area.

The Task Force believes that a demanding warfighting customer is essential to understanding the best use of ADS. Appendix B of this report lists twelve (12) recommended demonstrations. These demonstrations will provide a catalyst for the DOD and the commercial community to bring together requirements and technologies that are key to the future success of an integrated ADS capability.

Appendix C of this report evaluates the requirements of long range sensing and attack systems that will require integration in the overall analysis process. Integration of these key systems is important because they observe a wide area of interest to include both friendly and enemy forces, their coverage transcends all force elements providing important interfacing capabilities of joint or coalition forces, and they offer the potential for augmenting range instrumentation and providing ground truth in the testing environment.

In this study, the Task Force fully explored all of the terms reference (page iii) and focused on three key aspects: (1) assessing the impact of ADS on requirements, prototyping, development, training and readiness, (2) defining new ways to exploit the potential for convergence of live, virtual, and constructive simulation methods, and (3) providing recommendations on science and technology initiatives. It is the belief of this Task Force that ADS technology can greatly improve training and readiness, will help expedite prototyping, and can transform the acquisition process from within. It is being adopted by the warfighters but it can be exploited in a much larger context.

These assertions are based on a judgement concerning confidence. The Task Force has found that the wax-fighting community has embraced ADS and is extending its utility. Through its power, the warfighters are applying distributed and multiple simulation methods to improve planning, training, and mission rehearsal. The crux of the matter is that they have developed the confidence to use this technology to prepare for the most serious of circumstances where human lives are at stake. Additionally, ADS technologies can provide the confidence building needed for the transforming change in the acquisition process.

Five major recommendations for action are contained in the main body of the report, beginning on viewgraph number 30. Recommendation number two already has been implemented.

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DIRECTOR OF DEFENSE RESEARCH AND ENGINEERING

WASHINGTON, DC 20301-3010

14 APR 1992

MEMORANDUM FOR CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Terms of Reference - Defense Science Board Task Force on Simulation, Readiness and Prototyping

I request you initiate a DSB Summer Study Task Force to examine and make recommendations on the impact of advanced distributed simulation technology on service and joint readiness, to include an examination of recent and forecasted advances in large scale simulation technologies that may provide the capability to simulate a battlefield, including systems which have yet to be built and tested. The task force should brief its findings and recommendations to me in August and submit a final report in October. The task force should be supported by government advisors from OSD, DARPA, the Joint Staff, and the Services. Close coupling and active interaction among the three DSB Summer Studies is necessary to ensure the highest quality results. Your final recommendations should be structured as a series of action items, which, if implemented, would achieve the desired results.

Your examination of advanced simulation technology should include its application to: requirements definition: program planning and assessment; design and development of defense hardware; test and evaluation; operations, mission planning, dress rehearsal, and after mission review. The focus should be on understanding and defining ways to exploit the potential of the convergence of three types of tactical engagement simulation: virtual (as with SIMNET-like netted simulators), constructive (as with models and war gamer.), and live range exercises (as with the instrumented ranges in the southwest United States).

The task force should assess DOD investments in this type of technology by examining technology roadmaps and user plans to exploit and demonstrate this technology, and should provide recommendations on science and technology initiatives to mature the technology and its applications. In addition, the Task Force should explore the use of simulation of proposed prototypes as a management tool that could potentially shorten the time to conduct technology assessments and requirements analysis while also helping the user to determine how best to fight with these systems and technologies <u>before</u> committing to development.

The task force will be sponsored by DDR&E. Dr. Joseph Braddock and General Maxwell Thurman, USA (Ret), will be the Co-chairmen, Colonel Jack Thorpe, USAF, will be the Executive Secretary, and Commander Steve Wiley, USN, will be the DSB

Secretariat representative. DARPA will make arrangements and provide funding for a support contractor, should one be required, and will fund all necessary travel. It is not anticipated that this study will cause any member to be placed in the position of acting as a "procurement official" for the purposes of section 27 of the Office of Federal Procurement Policy Act.

Victor H. Reis

DEFENSE SCIENCE BOARD TASK FORCE REPORT

1 Opening Remarks

This report presents the findings and recommendations of the Defense Science Board (DSB) Task Force on Simulation, Readiness, and Prototyping.

This task force was chartered on 14 April 1992 and studied this issue from April through August, collecting and analyzing information and formulating the conclusions and recommendations.

The sponsor was Dr Victor Reis, Director, Defense Research and Engineering (DDR&E), Office Secretary Defense (OSD).

Impact of Advanced Distributed Simulation on Readiness, Training and Prototyping

16 Dec 92

2. Task Force Membership

The Task Force was co-chaired by Dr. Joseph Braddock and General Maxwell Thurman, and consisted of a group of Defense Science Board members and Consultants, a larger group of government advisors and a support group from the Defense Modeling and Simulation Office (DMSO), the Institute for Defense Analyses (IDA), and SAIC, Inc. (under contract to the Defense Science Board). LTC John Fair, U.S. Air Force, served as the Executive Secretary.

TASK FORCE MEMBERSHIP

Co-Chairmen:

Dr. Joseph V. Braddock
GEN Maxwell R. Thurman, USA (Ret)

Members:

Mr. Gordon R. England
GEN Paul F. Gorman, USA (Ret)
Dr. Anita K. Jones
Dr. Barton Krawetz
Mr. Donald C. Latham
Mr. Verne L. Lynn
Dr. Duncan C. Miller
RADM Charles R. McGrail, USN (Ret)
Mr. Gerald J. McNiff
Dr. Ivan E. Sutherland
Dr. James T. Tegnelia
Mr. Samuel M. Tennant
Gen Larry D. Welch, USAF (Ret)

Executive Secretary:

LTC John Fair

Government Advisors:

Mr. Charles E. Adolph
COL Gil Brauch
COL Harvey Dahljelm
Dr. Gary Denman
COL Bernard Ferguson
COL Ed Fitzsimmons
LTC Robert Fleming
COL Steve Funk
COL David Haughey
LTC Paul Hinote
Mr. Frank Hoffman
Mr. Ralph Johnson
Mr. William Kincaid
COL Wendell Kot
CAPT Ernest Lewis
CDR Michael Lilienthal
RADM(S) John M. Luecke
Mr. Dell Lunceford
MG James M. Lyle
CDR Joseph O'Donnell
LTC Daniel Pierre
LTC Roger Robichaux
MG Alan V. Rogers
Dr. Patricia Sanders
Mr. Joseph Santilli
Dr. Ernest Seglie
COL James Shiflett
Dr. Michael Sullivan
COL Jack Thorpe
Mr. James Vernon
COL(P) David Vesely
COL Leonard Walls
MAJ Frank Wysocki
Mr. Richard Woodard
Mr. John Yuhas

Support Staff:

Mr. Paul Chatelier
Mr. James Chung
Ms. Biddy Ditko
Ms. Debbie Edenton
Ms. Carrie Sigman
CDR Steve Wiley

3. Terms of Reference

The Task Force was asked to examine three major issues. First, it was to assess the impact of a new technology - Advanced Distributed Simulation (ADS) - on requirements, prototyping, development, training and readiness. Second, it was to find ways to exploit the potential for the convergence of the three forms of simulation methods. It is in the convergence of live, virtual and constructive methods that the new capabilities could emerge. Third, the Task Force was to provide recommendations on priorities for science and technology initiatives.

TERMS OF REFERENCE

- Assess impact of Advanced Distributed Simulation (ADS) on requirements, prototyping, development, training and readiness

- Define ways to exploit potential for convergence of live, virtual, and constructive simulation methods

- Provide recommendations on Science and Technology Initiatives

4. We Believe

The Task Force became convinced that ADS technology is here today and can have a major impact on both readiness and training as well as the requirements-through-fielding process.

This technology can create an environment for operational and technical innovation which could lead to revolutionary improvements and it can be used to transform the acquisition system from within. The Task Force believes that the evidence for Bullets 1 and 2 is conclusive and for Bullet 3 is strongly indicative.

It is also the Task Force's judgment that the technology in a useful form is here today and should be applied to the set of problem areas and functions described previously. Having said this, a DOD investment is required to further mature the technology and to fill voids and gaps.

Finally, the Task Force is convinced that ADS will not only lead to substantial performance improvements but it will also save money.

WE BELIEVE

That this technology can provide the means to:

- Improve training and readiness substantially
- Create an environment for operational and technical innovation for revolutionary improvements
- Transform the acquisition system from within

The technology is here today - - - DOD investment required

Its Adoption Will Save Money

5. Outline

The remainder of this briefing is organized into two parts. In the first, we compare and contrast pre-ADS with ADS activated in training, prototyping, and test and evaluation. With these we shall establish feasibility, affordability and future promise. We will then review a technology assessment which establishes today's capabilities and tomorrow's technology priorities.

In the second portion of the briefing, the Task Force recommends an approach which is intended to fully exploit current ADS capabilities in the very near term. It has an experimental character and is based on the thesis that a demanding and well informed warfighting customer will pull the needed innovation.

OUTLINE

- Definitions
- Historical and current examples and status
- Technology Assessment

- Opportunities & Vision
- Experimental Approach
- Recommendations

6. EVERYTHING IS SIMULATION EXCEPT COMBAT: THREE METHODS OF SIMULATION*

Military leaders are well aware that no simulation adequately portrays the stress and chaos of war, but they also know that training saves lives and assures victories, and that some simulations are better than others.

Earlier in the Terms of Reference, we focused on the convergence of the three methods of simulation. To start we review each method in detail.

LIVE-

The **Live** component of simulation involves operations with real forces and real equipment in the air, on the ground, on and below the sea. Examples include large scale, live exercises such as the Army's Reforger, the Air Forces Red Flag, activities at the Army's National Training Center, Navy's Strike University at Fallon Field. Also included are hardware prototypes, a live simulation of an intended system. Often these wide ranging live activities are not thought of as simulations, but they clearly are.

CONSTRUCTIVE-

In the second category, labeled **Constructive,** are included wargames, models and analytic tools. A number of these developed by the individual Services are shown on the right hand side of the chart.

VIRTUAL-

The third category is called **Virtual.** This is a relatively new simulation technique in its current form. Here systems are simulated both physically and electronically. Real people fight on synthetic battlefields. Forms of virtual simulation that involve networking include the recently developed SIMNET (Simulation Networking), BFTT (Battle Force Tactical Trainer), individual aircraft simulators and *virtual* prototypes which we shall examine in greater detail.

The Gulf War demonstrated that various simulation tools can go to war and be highly effective. J-STARS, a prototype, went to war. Virtual simulations of F-14 engagements went to war to see if it was possible to engage Scud missiles during their launch phase. Prototype and ad hoc information systems went to war in the Gulf. Examples of these were the JIPC (Joint Intelligence Processing Center) and the ad hoc wiring which brought DSP (Defense Satellite Program) and other early warning information to that theater.

We have heard testimony from many veterans of the DESERT SHIELD/STORM on the importance of regarding modern simulations as part of any command's battle equipment, for constructive simulations figured prominently in testing plans and rehearsing battle staffs, and live and virtual simulations honed battle skills. But all agreed that the Services have not gone far enough in providing such tools to warriors preparing to go into action, wherever they may be.

"Simulation" is defined in* *Webster's New Collegiate Dictionary* *as "…. a means for examining* **a *problem . . . . . . ", and it is in this sense that most scientists and engineers have encountered the word. But in military parlance, "simulation" has a broader meaning, in that it encompasses ways of anticipating the problems of combat for the purposes of training, as well as analyzing or evaluating materiel.*

EVERYTHING IS SIMULATION EXCEPT COMBAT

EXAMPLES

Operations With Real Equipment in the Field = **Live** →

- REFORGER
- Red Flag
- NTC
  - Breeching Tactics
- Strike University
- Prototypes
  - JSTARS

Wargames, Models, Analytical Tools = **Constructive** →

- CBS (Army)
  - BCTP
- AWSIM (Air Force)
- ENWGS (Navy)
- TACWAR (Joint)
- TAC Brawl& (A/r Combat)
- Checkmate Asessments (Joint)

Systems and Troops in Simulators Fighting on Synthetic Battlefields = **Virtual** →

- SIMNET
  - ODIN
- Battle Force Tactical Training (BFTT)
- Aircraft Simulators
- Virtual Prototypes (NLOS, LOSAT)

Simulations and Prototypes Go To War

7. ADVANCED DISTRIBUTED SIMULATION (ADS)

What is Advanced Distributed Simulation (ADS)?

First, advanced applies to the circumstance that permits the use of a common core technology across the spectrum of Defense uses, from training and readiness through the requirements -thru- prototyping -thru- fielding process.

The second property of this technology is that it is distributed. There is a shared battlefield. It has an electronic form which is identical for geographically separated activities. A communications network is used to integrate and synchronize these activities.

Simulation in this context refers to the mix and matching of live, constructive and virtual simulation methods. In some cases, two techniques are used and in other cases, all three might be used.

ADVANCED DISTRIBUTED SIMULATION (ADS)

Advanced: Applies to all training and readiness and the requirements prototyping process with the **same core technology base**

Distributed: **Shared battlefield** entered from geographically separated sites via communication networks

Simulation: **Mix and match** of live, constructive, and virtual simulation methods

8. VIDEO TAPE: DDR&E BRIEFING TO THE SENATE ARMS SERVICES COMMITTEE, 21 MAY 92

To illustrate the potential of this new technology, the Task Force submits a video record of the DDR&E briefing to the Senate Armed Services Committee* made during a testimony presentation in May 1992.

In this tape, General Paul F. Gorman, U.S.Army (Retired), a Task Force participant, led the presentation of this technology to the Senate Armed Services Committee. He demonstrated how simulators in the Senate Armed Services hearing room and simulators in other parts of the country could be linked in real time to bring weapon systems together on the same battlefield. The chosen common terrain was a representation of Ft. Hunter Liggett in California. The participants located in the hearing room included an F-16 simulator, an AH-64 attack helicopter simulator, an OH-58D simulator was flown from Ft. Rucker, Alabama, and a platoon of M-l tank simulators were operated from Ft. Knox, Kentucky. Other vehicle simulators, including warships, were connected. Of note, the LOSAT simulator was an electronic prototype of a notional system whose components have been partially developed and even tested but for which there is no weapon system in the inventory at this point. A LOSAT (Line of Sight Anti-Tank weapon system), virtual prototype simulator.

The power of the technique described here is obvious. The different combatants were brought together on a common battlefield using virtual simulators, virtual prototypes and a network of communications adapted for these purposes using commercially available components and services.

** In early May of this year, the staff of the Senate Armed Services Committee notified Dr. Reis, DDR&E, that Senator Nunn wished to hold a hearing in the subject of Advanced Distributed Simulation, and its potential for assisting in the training of the Active and Reserve Components.*

In mid-May, DDR&E proposed, and the Chairman accepted, a proposal to hold the hearing on 21 May, with witnesses as follows:

- *General Paul F. Gorman, USA (Ret), a former CINC and Army trainer.*
- *Captain H. R. McMaster, Armor, USA, commander of Troop E, 2d Armored Cavalry Regiment during DESERT STORM*
- *Dr. Victor Reis, DDR&E*

Within a week of the decision to proceed, a communication network was arranged, and simulators were moved to Washington. They were installed in the Dirksen Senate Office Building, checked out, and began operation within 24 hours. While there were functional checks of the networks and simulators, the testimony itself was essentially unrehearsed. The Defense Modeling and Simulation Office (DMSO) coordinated this effort, and the Institute for Defense Analyses (IDA) acted as the point of integration.

During the three hours of testimony:

- *General Gorman reviewed major developments in Service training during the 20th Century.*
- *Captain McMaster used and ADS simulation to show how his troop operated in the Battle of 73 Easting.*
- *Using virtual, distributed simulation, General Gorman and Captain McMaster staged an impromptu ambush of a column of T-72 tanks advancing up a valley in California.*
- *Dr. Reis presented a vision of the potential of ADS for R&D, test and evaluation, training and operational rehearsals, and discussed how this capability was an essential part of the new DOD Science and Technology Strategy.*

-VIDEO TAPE -

DDR&E LIVE DEMONSTRATION TO SENATE ARMED SERVICES COMMITTEE 21 MAY 92

9. ADS CAPABILITY - WHAT IT IS NOT

While much can be done with ADS technology, the Task Force has attempted, and we believe succeeded, in maintaining a balanced view of this technology and its impact.

It is not a replacement for live training or for testing. Neither is it a mechanism for central control of Service training. Nor is it a substitute for engineering development and it is a technology which is not yet fully technologically mature.

ADS should not be thought of as a replacement for steaming days, flying hours, or op tempo for ground forces. It is a complement. Its other forms would underwrite the possibility of improving the training state of forces which would undertake live training. This Task Force does not recommend trading off expenditures for ADS vs. decreased expenditures for live training.

It is not a mechanism to supplant the Service training which goes on today. The Services are to be complimented on the advances they have made in training over the past thirty years. At their individual live training sites, the Services have provided a very competent opposed force, and all the stresses and environments which it is possible to provide within the limits of safety and cost. Pervasive instrumentation systems provide an objective evaluation of the training activity and after action review analysis. These are the essential ingredients for all forms of simulation that bear on preparing forces for combat and for specifying and developing material.

Virtual prototypes, simulated test environments, and other simulation support for acquisition can transform the approach to defining requirements, assessing feasibility and risk, and early assessment of capabilities. However, ADS will not substitute for the detailed work of engineering development, concurrent engineering transition to production and other activities required to translate virtual systems to fielded capability.

ADS can provide important insights into the development process. Indeed, today extensive simulation is used to support development. It is, however, simulation of one kind or another and does not employ combined methods, nor is it networked. It is in the power of ADS multiple methods, man-in-the-loop and networking that advances can be made in the engineering process with a combination of live, virtual and constructive simulation. Again, there is no substitute for the live portion of the simulation. We believe that it is possible to speed the process whereby live components are developed. This speeding of the process may include skipping steps. The basis for skipping steps is confidence - confidence developed from knowledge, and insights developed through combined methods of simulation including live engineering development.

ADS technology is not fully mature. We shall see in a later section of this report exactly what is its state of maturity, the aggressiveness of its funding and where there are voids.

ADS CAPABILITY - WHAT IT IS NOT

- A replacement for live training or testing
- A mechanism for joint scheduling of Service training
- A substitute for engineering development
- Fully technologically mature

10. WHERE CAN WE USE ADS TODAY?
Some Things We Do Well

Where may ADS be used today?

One can examine the application and impact coming from two perspectives. On one hand we could consider what we are doing well and ask and answer the question, "Where can we do better?" On the other hand, we can examine situations where we do not do well.

The Task Force has chosen to do the latter, but to maintain balance, addresses here what we do well.

The Services train individual soldiers, sailors, airmen and marines and provide highly trained combat units and do a very good job. We discussed previously the underlined principles of competent opposed force, all of the necessary environments, and an objective form of feedback concerning activities and outcomes. The Services have spent resources and committed people to make sure that this indeed was and is the case and no other army, air force or navy, or marine corps trains the way that those of the United States do.

In the same vein, experience has shown that we develop and field high capability systems and we use objective testing hardware against these same components that are used in training, e.g., a competent enemy, relevant environments and objective feedback.

While there are opportunities to make improvements in these areas, we have not focused on them but have chosen to focus on things that are not done well.

WHERE CAN WE USE ADS TODAY?

- ***Some things we do well:***
  - Train the **individual** soldier, sailor, airman and marine
  - Provide highly trained, **combat ready units** via the Services
  - **Develop** and field high capability systems
  - **Test** hardware systems against specified performance requirements
  - And much more. . . . .

11. WHERE WE CAN USE ADS TODAY (Cont'd)
Some Things We Don't Do Well

Some things we don't do well. First and foremost amongst these is the training and exercising of large, joint or combined forces to fight on short notice. Our joint force exercises are scheduled a year or more in advance and they are very costly. In some instances, our Allies participate. The realism in such exercises has been steadily increasing but the majority of participants get little useful training. It is not possible today to convert a Joint Task Force Commander's concept of operation into a realistic rehearsal tomorrow. The same is true for a short notice examination of alternative force packages for a contingency crisis.

Achieving joint interoperability remains a challenging problem. There are currently over 300 C^4I systems, many of which do not interoperate. There are also doctrine and concept disconnects. During the Gulf War, ad hocery was employed to solve many of these problems. The solutions have been dismantled. We believe ADS technology could help in the planning associated with ad hocery, now we find that and some if not all of the solutions.

During the Gulf War, instances arose where National Guard ground combat forces were judged to be inadequately trained and ready for combat. This is not a surprising result since the time and effort available to train Guard and Reserve forces is very limited. ADS technology could improve some of these circumstances.

Another lesson learned from the Gulf War had to do with the integration of National Technical Means site planning, assessment, allocation of forces, execution of operations and damage assessment. Much data was delivered. In many instances, it was inefficiently used or not used at all. It is our belief that ADS technologies can provide the circumstances to train and exercise together in peacetime.

Establishing the military worth of new concepts or new hardware is always a difficult process. Here again we believe we can demonstrate that ADS technology can provide a major assist.

Finally, and not exhaustively, the prescription of standards and protocols for internetting and interconnecting advanced simulations are today little more than permissive. Commercial and government standards and protocols are not always compatible. We could easily have an ADS system architecture which does not leverage the enormous and essentially free investment in commercial technology which is available.

WHERE CAN WE USE ADS TODAY? (Cont'd)

- ***Some things we don't do well:***
  - Train and exercise large combined forces to fight ***jointly on short notice***
  - Develop, test and assess **interoperable** C4I, doctrines, and concepts
  - Train Reserve ground combat forces
  - Integrate and **evaluate output of National Technical Means**
  - Assess the technical feasibility, cost, schedule and ***military worth*** of systems in concept formulation
  - **Prescribe** standards and protocols for internetting

12. Example: REFORGER 1988 vs 1992

We now examine the first of three examples of the application of ADS technology and compare it to earlier forms of simulation,

In 1988, the Army employed nearly 100,000 troops in a major NATO exercise, transporting over 17,000 from the United States alone. Essentially, two Corps were deployed, one simulating the opposing force (a notional Soviet force) and the other operating as a U.S. force.

Umpires were used to evaluate outcomes and intelligence was pre-scripted. In evaluating this exercise, senior commanders judged that training was useful at the upper levels of command, but at battalion and below it was negative training since these forces were really training aids for higher levels of command. There was essentially no information taken home to evaluate what happened, what went right and what was done incorrectly. The cost for this exercise was nearly $54 million dollars of which $20 million was maneuver damage. It was the largest Reforger exercise performed.

In September 1992 there will be another new Reforger exercise which is underwritten with advanced distributed simulation techniques. It is a combined live-constructive exercise. There are only 6,500 troops being ferried to Europe, a total of 20,000 on the ground, and many fewer vehicles.

The combined simulation methods in 1992 create circumstances for an exercise twice as large as Reforger '88. The operational problems addressed involve NATO as well as national forces. There is free play with an intelligent opposed force operating at Ft. Leavenworth, Kansas. There are real sensors and simulated sensors providing feedback. All troops, including those at home stations such as the 4th Mechanized Division at Ft. Carson, Colorado, received positive training. There is for everyone, at each level of command, an analytic data package to describe what happened and how it happened. The cost for this exercise is less than $20 million dollars.

In comparing these two exercises, the current ClNC USAREUR, General Maddox, judges that all parties involved, U.S. and NATO will receive much more powerful training through combined methods at a lesser cost.

Personal Evaluation of General Maddox, C/NC USAREUR, 17 Aug 92:

" • Reduced cost.

• FTX of this magnitude politically not possible.

• Because of free play of the OPFOR in simulations, all players are on the friendly side. At essentially the same headquarters count, the operation has gone from a friendly Corps versus an enemy Corps, to a multinational allied army group with two plus Corps fighting an enemy front with two armies. The result is a significant enhancement in training as the Corps operate under an operational headquarters and must coordinate with each other.

• Soldiers in small units are free to continue meaningful training while headquarters elements participate in the CAX. Squads, crews, teams, sections, platoons, and companies were training aides in the old FTX version REFORGER. Negative training occurred as battalions were maneuvering in column on roads. These soldiers are now conducting meaningful, small-unit training, while their senior headquarters are participating in the REFORGER CAX.

• Joint training is significantly enhanced by the integration of air and ground simulations. Air operations have an immediate effect on ground operations. Ground air defense and SEAD also have a direct effect on air operations.

• Intel tasking and anaylsis have a direct impact on operations, as the simulation now provides sensor level feedback rather than scripted intelligence estimates. In FTX real sensors often were not used (particularly national technical means) and the FTX formations were not properly deployed to allow for proper intel collection.

• Capability exists to capture situation data in the simulation for later analysis or follow-on training. Given the magnitude of previous REFORGER exercises, this data was never available for follow-on analysis and training."

Example: REFORGER 1988 vs. 1992

	LIVE	ADS
	1988	1992
	17,487 Deploying Troops	6,500 Deploying Troops
	97,000 + Soldiers 7,000 Tracks 1,080 Tanks	20,000 + Soldiers 135 Tracks 0 Tanks
Maneuver HQ	35	41

Represents:
175,000 Soldiers
12,810 Tracks
1,950 Tanks

EXERCISE SCALE	Corps vs. Corps	Army Group (2 Corps) Vs. Enemy Front (2 Armies)
STYLE	Umpire	Free Play / Intelligent OPFOR
INTELLIGENCE PLAY	Scripted	Sensor Level Feedback
BATTALION & BELOW TROOPS	Negative Training (Columns on Roads)	Positive Training (Troops At Homestation)
TAKE HOME	Anecdotal (Data not Available)	Analytic Data Available For Follow-on Training
COST	$53.9M	$19.5M

More Powerful Training Through Combined Simulation Methods - Lesser Cost

13. Example: TANK PROTOTYPING 1984, 1986, 1992

An early example of tank prototyping provides us with additional insights of the power of ADS.

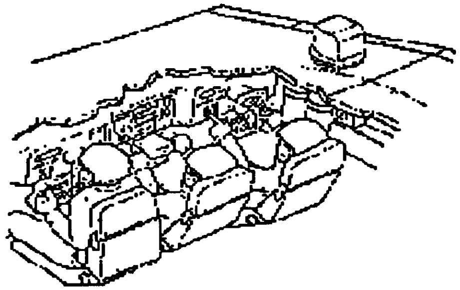
In 1984, General Dynamics and the Army undertook the development of a test bed (a live simulation). It involved an upgraded M-l with improvements to the loader and the fire control system. After two years and $40 million, the prototype was not yet functional.

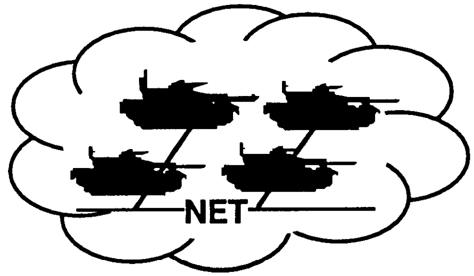
At that point, the venue for simulation was shifted to a modified aircraft dome. The M-l configuration in question was simulated by altering the computer software for the dome and by appropriately adjusting altitude and speed. Several variations of the M-l, above and beyond the modified loader and fire control, were examined. All objectives of the program were achieved. The marginal cost of the virtual simulation was one million dollars and the project was completed in six months.

Currently, the Army has an unusual prototyping activity underway. It involves using the SIMNET facility and examines improvements to the M-l evaluated at the platoon and company level. Four variations of the M-l are being considered and the technology in the opposing force is the German Leopard 2. The concern here is technology transfer and where Army and Marine forces of the future might meet not only the more or less the expected equipment of the former Soviet Union but also Western technology. This evaluation activity is underway, is expected to cost $640,000 and should be finished in a three month period.

Advanced distributed simulation, in this instance, offers substantial potential to improve and shorten the time taken in the requirements definition -thru- prototyping process.

Example: TANK PROTOTYPING 1984,1986,1992





• Live simulation (real hardware)	• Virtual simulation (modified aircraft dome)	• Virtual distributed simulation
• Point design w/upgraded: – Loader – Fire Control	• One configuration (MlA2) with variations	• Four variations of the Ml tank vs. Leo II class threat
• No results (never functional)	• Achieved objectives of live simulation	• In process
• When: 1984 - 86	• 1986	• 1992
• $40M / 24 months	• $1M / 6 months	• $0.64M / 3 months

[Marginal Costs]

14. Example: OPERATIONAL TESTING OF NLOS 1988, 1989

A third example is excerpted from an operational test conducted by the Army's Operational Test and Evaluation Command (OPTEC) reported in October 1991 (OA-1394, Independent Operational Assessment of the Non-Line of Siaht Simulator and the Defense Simulation Network As User Testina Tools.

OPTEC is responsible for performing operational tests at various stages of development. Starting early in 1988, OPTEC conducted a test of the non-line of sight prototype in an environment where real helicopters simulating an enemy force were engaged on an instrumented range. This test proceeded for thirteen months and its total marginal cost was $15.5 million dollars.

The non-line of sight system is a vehicle mounted missile which has a range of approximately 20 kilometers and employs a fiber optic data link to carry information from its sensor to the gunner. Earlier is was known as the FOG-M. Various versions of the NLOS are being considered for engaging armored targets and helicopters. In this test, the engagement was against helicopters. This was an early operational test to assess the concept, its requirements, and the hardware, along with its adaptation by forces.

After the test was completed, the OPTEC conducted a parallel evaluation of the use of distributed virtual simulation (ADS) using an NLOS simulator at Ft. Knox and helicopter simulators at Ft. Rucker on a common terrain data base (Ft. Hunter Liggett). The test took three months and cost $2 million dollars.

The purpose of the second operational test was to assess the utility of distributed virtual simulation to meet only operational test and evaluation requirements.

The following are excerpts from the Executive Summary of the report.

The NLOS/SIMNET system was highly effective.

a Personnel test time in total dollar cost were significantly reduced.

b. The NLOSlSimnet system had a mean time between operational mission failure of 72 hours and operational availability of 0.99 and a mean time to repair of 18 minutes.

c. Important system functions and characteristics were generally rated as being realistic by system operators and subject matter experts.

d. Data base management software indigenous to the system was effective. Results generally support the future use of weapon systems simulators requiring optics, CRTs and out of window views in the simulated battle environment early in the acquisition process. The simulator Simnet system concept should be considered for incorporating into the testing strategy during the early development of stages of Army weapon systems. Its implementation should assist the material developer in defining weapon system characteristics and capabilities and should assist the combat developer in defining operating procedures and tactics.

All in all, the use of ADS technologies were shown to be very effective in the case where a complex combined infantry and air defense system was being examined in early operational testing.

Example: OPERATIONAL TESTING OF NLOS* 1988, 1989

COMPARISON	
• Live simulation – NLOS Prototype – Helos – Instrumented Range • $15.5M / 13 months	• Distributed Virtual Simulation – NLOS simulator (Ft Knox) – Helo Simulator (Ft Rucker) – Common terrain data base • $2M / 3 months

Objective:

- Assess utility of distributed virtual simulation to meet OTE requirements.

Results:

- Virtual distributed system highly effective

Recommendations:

- Concept should be considered for testing early in development

** Non line-of-sight system*

Source: USA OPTEC Report

15. Video Tape: F-117 MISSION PLANNING SIMULATION

The video tape presented here is approximately 2 minutes long. It shows a visual display of the results of virtual simulation of the F-117 penetrating a defended area to engage a target. The simulations in question are constructive and can be coupled into the virtual simulator and of course interfaced to a human pilot.

These combined tools are appropriate for setting specifications, developing requirements, undertaking an assessment of testing to be conducted, examining hardware and requirements tradeoffs, and finally, in training, readiness and mission planning.

- VIDEO TAPE -

F-117 MISSION PLANNING SIMULATION

16. DEFENSE SIMULATION INTERNET (DSI)

Up to this point, we have been examining various combined methods of simulation without addressing how the interconnections take place. Over the past several years, the Defense Simulation Internet has been developed to perform such tasks.

DARPA, in cooperation with DISA and DMSO, is fielding this testbed for distributed simulation. Developed from DARPA's latest contribution to operational networking, the "Terrestrial Wideband Net", the Defense Simulation Internet (DSI) will continue to grow from its current 50 sites worldwide. Communities represented include Distributed Interactive Simulation for training, test and evaluation; distributed wargaming for readiness; Joint Staff, CINCs, and War Colleges for analysis; and Instrumented Ranges for integrated simulation.

Within the United States, the Internet employs long haul lease communications adapted through protocols and standards to the various terminals and simulators and command control equipment required to mount the sorts of exercises, experiments and tests which have been previously described.

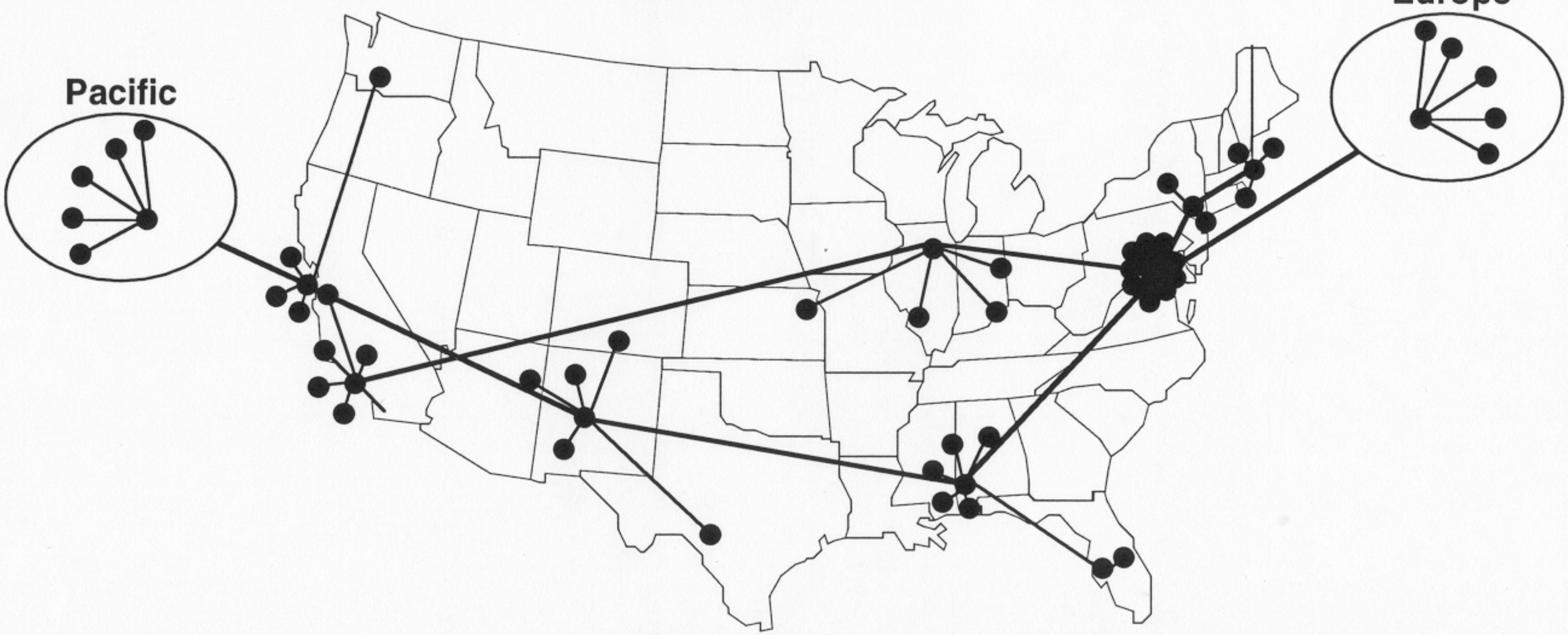
The DSI is built on the commercial communications base with today's 1.5 megabit per second backbone links eventually going to 45 megabits per second. It will transmit secure data, video, voice and graphics between sites, using advanced protocols that support resource reservation and efficient sharing of resources for real-time simulation. Plans exist for transition of the DSI to the next-generation Defense network to be operated by DISA.

The current network is extended to Europe and to forces in the North Eastern Pacific through fiber optics cables and satellite corn munications. A variety of nodes and a network exist at each end of this long haul network.

Users are connected to this network through terminal equipment whose cost and sophistication depends upon security requirements. Initial connection costs run from $150,00 to $300,000 depending on level of security. The network is available for use by industry, academia, active, Reserve and Guard forces and is available for training, concept development and for prototyping.

DEFENSE SIMULATION INTERNET

It's Available Now and Should Grow . . . .



- Connect Charge: $150K - $300K

- Room for industry, academia, active and Guard Forces, for training, concept development, prototyping

17. OPERATIONS USING THE DEFENSE SIMULATION INTERNET: ULCHI FOCUS LENS

Combined forces command in Korea headed by General Robert RisCassi conducted an exercise called ULCHI Focus Lens in August and September 1992. This was a combined live and constructive simulation which employed available ADS technology. Elements of his command and some of their forces in Korea were connected through a central node at Combined Forces Command. Others were at Osan and Suwan air bases, at Camp Casey and at Walker Center. Undersea fiber optics and satellite communications connected Pacific Command in Hawaii and the U.S. including I Corps, the Joint Staff and a network operation center in Boston. Continuing across the United States to Europe by satellite and fiber optics connections to the Warrior Preparation Center in Einsledlerhof, Germany.

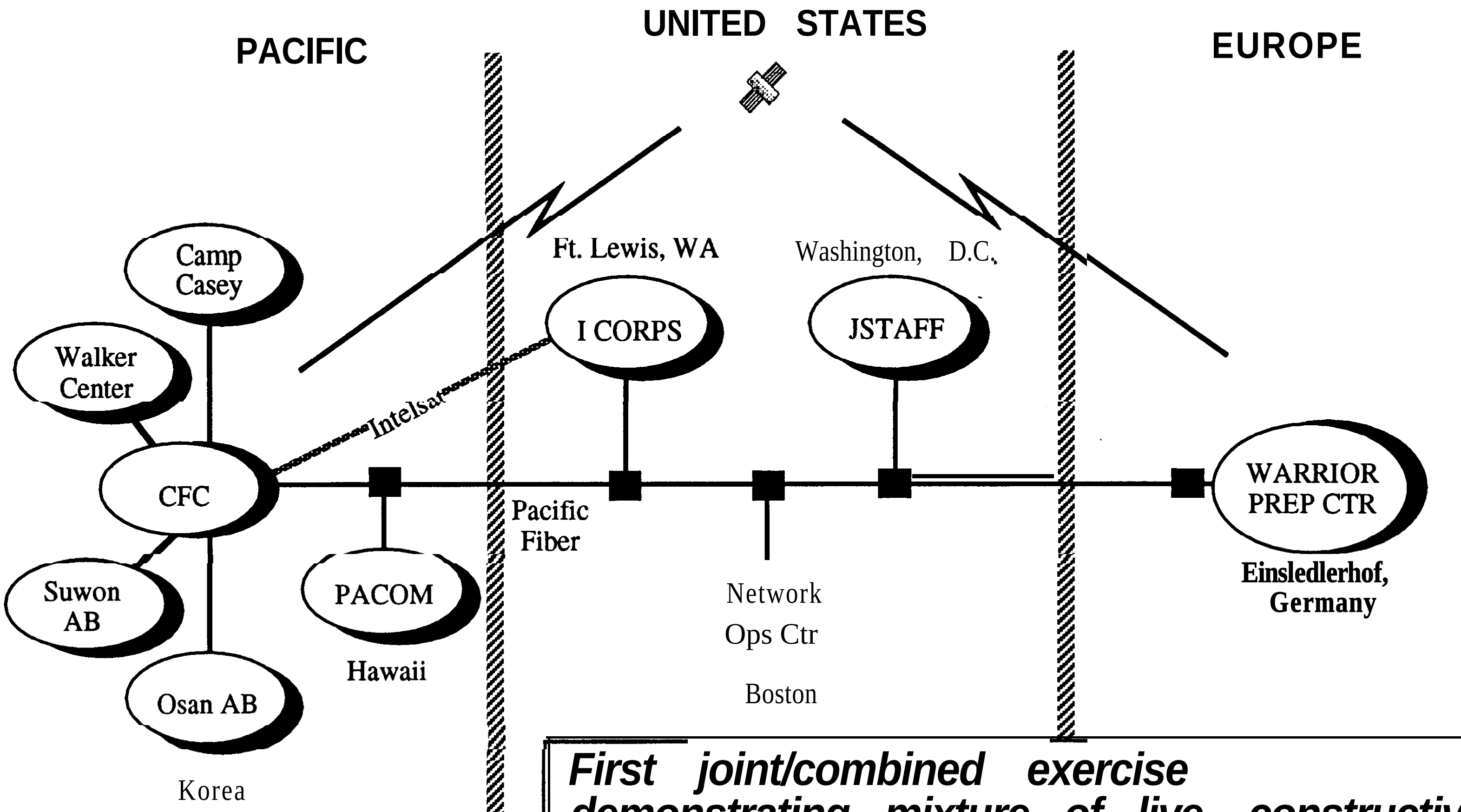
The constructive simulation software used in this exercise were run at the Warrior Preparation Center in Germany. This was done because of the level of expertise available at this facility and the capability of networking to provide it to Combined Forces Command as though it was physically available.

The duration of ULCHI focus lens was 20 days. The first 13 days were a command post exercise and the last 7 days included a field training exercise. During the latter phase, the same network was in place and was used to examine and evaluate concepts, procedures, and those systems and forces that on to engage critical targets. General RisCassi's command had a staff element called the Integrated Target Operations staff which was the central element in this activity.

The opposed force in the CPX portion of the exercise was implemented through constructive simulation means. For the field training exercise, the opposed force lied across the demilitarized line.

The exercise was supported by the Army's Corps Battle Simulation (CBS) running in Korea, interoperating with two models running at the Warrior Preparation Center (WPC) in Germany: the Air Warfare Simulation (AWSIM) and the RESA naval model. The models interoperated using the Aggregate Level Simulation Protocol developed by DARPA.

OPERATIONS USING THE DEFENSE SIMULATION INTERNET: *ULCHI FOCUS LENS*



First joint/combined exercise demonstrating mixture of live, constructive, distributed simulations, and linked to command and control systems

18. OPERATIONS USING THE DEFENSE SIMULATION INTERNET: REFORGER '92

In September 1992, U.S. Army Europe conducted Reforger '92, the "Return of Forces to Germany," (REFORGER). This was the first REFORGER exercise by the U.S. Army, Europe, to be totally simulation-based. U.S. Army Europe refocused REFORGER to do more for less by using the Army Corps Battle Simulation (CBS) and Air Force Air Warfare Simulation (AWSIM) models linked via the Aggregate Level Simulation Protocol. In addition, access to simulations via organic C^3I systems and use of the Defense Simulation Internet (DSI) was implemented.

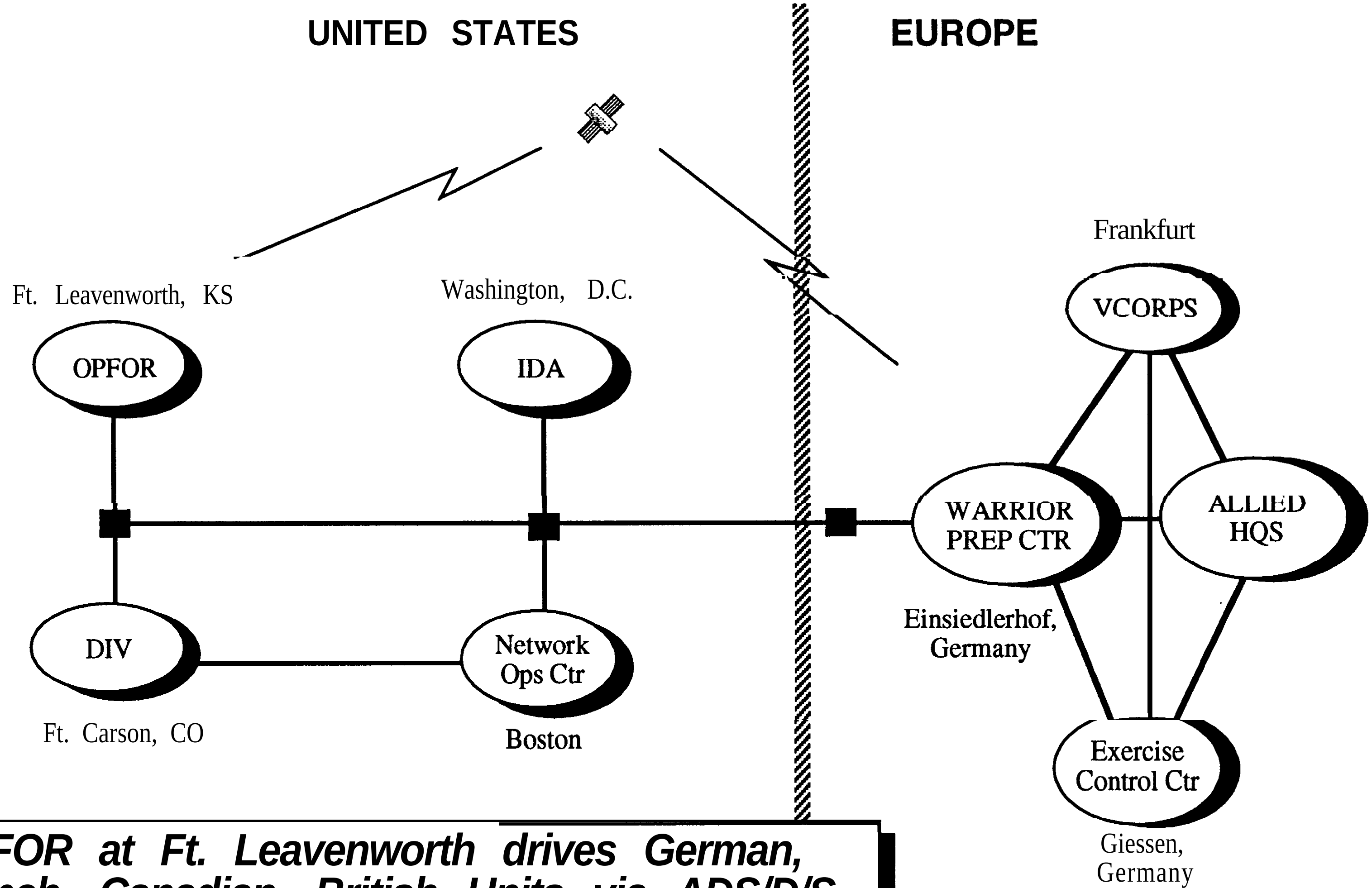
Reforger 1992 had unique aspects enabled by ADS technology. The European elements involved U.S. V Corps, Allied Headquarters through Army group, an exercise control facility, and the Warrior Preparation Center. These were networked by cable and satellite communications to an opposed force at Ft. Leavenworth, Kansas, elements of the 4th Mechanized Division located at Ft. Carson, Colorado, and other facilities which provided network control and the ability to unobtrusively observe the exercise.

This contrasted with previsous REFORGERs. For example, in 1988, the opposed force was played by a 50,000 man U.S. Corps; most of the personnel in the Corps received little training as a result of the exercise format and style. They were, in effect, training aids for higher levels of command. In REFORGER 1992, the opposed force was played by a 200 man unit at Ft. Leavenworth whose job is to serve as a full-time, professionally trained opposed force. This unit is highly skilled and is able to operate as an opposed force within the doctrines and procedures of several possible opponents. Here we saw another major benefit of the ADS approach; rather than 50,000 men and women, a 200 person team provided the same function. Additionally, this team provided the opposed force for all Allied forces. The elements in the exercise include German, British, Canadian and smaller elements of other NATO Central Region Allied forces.

In the four years since it became available in Europe, distributed netted simulation has changed the capability of commanders and forces to train, prepare, and implement innovation at a time when force size has been decreasing and the uncertainties threat mission have been increasing.

DSI linked three sites in Europe with four sites in the U.S., including a temporary site at Fort Carson, with fully redundant communications links for reliability. It operates as a secure capability to link combat workstations along with video, voice, and graphic interfaces.

OPERATIONS USING THE DEFENSE SIMULATION INTERNET: *REFORGER '92*



OPFOR at Ft. Leavenworth drives German, French, Canadian, British Units via ADS/D/S

19. ASSESSMENT OF ENABLING TECHNOLOGIES

We now transition to an assessment of enabling technologies. These fall in generally two categories: those that are provided by the commercial sector, mostly hardware, and those which DOD must provide. These turn out to be mostly software.

The commercial hardware ranges from integrated circuits, microprocessors, fiber optics communications in local and wide area networks, the technologies used in developing work stations, high performance computing adapted particularly to ADS, computer image generation systems (graphics), and generic man-machine interfaces.

These are adapted in the DOD context via software by developing models for various constructive applications, providing instrumentation for the live methods of simulation at ranges, developing realistic and effective semi- and fully-automated forces, providing simulators where there are no comparable applications in the commercial market, providing security, and at a higher level for other parts of the development activity, providing manufacturing process simulations and engineering design models and simulations. In general, our observations concluded:

- Commercially driven technologies provide a vast, critical base to enable DOD to realize the applications envisioned for modeling and simulation.
- DOD should continue to invest in very fundamental technologies which have both DOD and potential commercial spinoff. Examples are: low cost high definition displays and especially helmet mounted displays, high performance computing and parallel processing in particular, software engineering and expert systems in particular, and advanced networking.
- We identified twelve DOD-driven technologies which are key to DOD realizing the span of applications of M&S in the next decade or earlier. Our technology assessment conclusion, presented in detail in Appendix A, is that hardware generally is not an issue – it is coming along in the commercial world at a more than adequate pace. The real issues are software in general and fully and semi-automated forces in particular, databases and especially dynamic databases, protocols and standards across the M&S technologies, system level architectures, and the seamless integration of M&S for many diverse applications such as engineering design and manufacturing.
- The price/performance cycle of commercially relevant technologies is 2 to 5 years whereas the cumbersome DOD acquisition process is on a sure-obsolescence cycle much longer. This is a major issue of concern. The 5000.1 Defense Acquisition is inappropriate to the fielding of ADS. With an open architecture, a modular developmental approach should be more than satisfactory.

As implied by the foregoing, much ADS capability can be fielded with today's technology and services.

ASSESSMENT OF ENABLING TECHNOLOGIES

Applications

Technologies

Commercially Driven

- Microcomputer systems
- Telecomm/wide area networks
- Man-machine interfaces
- Computer Image Generator systems
- High performance computing systems*
- Memory
- Microprocessors
- Mass storage
- DBMS
- Displays
- A/D/A converters
- Local area networks
- Fiber optic communications
- Integrated circuits
- Software engineering tools

DoD Driven

- Manufacturing process simulations
- Engineering design models & simulations
- Manned simulators
- Stochastic wargaming simulations
- Semi-Automated Forces
- Instrumented range systems
- DOD databases
- DOD protocol standards
- Verification, validation and accreditation
- Multi-level security
- M&S construction tools
- Instrumentation

- Human behavior representation models
- Environmental representation models

Substantial ADS Capability Can Be Fielded With Today's Technology

* For ADS applications

20. FINDINGS FROM TECHNOLOGY ASSESSMENT

Therefore, we have concluded that we can rely on the commercial sector for the technology base for ADS. It is reasonable to anticipate that this sector will continue to produce a factor of ten improvement in price/performance every 2 to 5 years. However, continued DOD investment will be required in these areas unique to Defense ADS applications:

1) **Simulations Scalability (Virtual).**

For large scale, seamless applications of ADS, the architecture of the Defense Simulation Internet will need to transition from a full broadcast scheme, currently demonstrated for 1,000 discrete objects, to a discriminate broadcast scheme where band width between sites is dynamically allocated based upon battlefield interactions. This is a challenging research problem unique to simulation internetting and requires DOD support.

2) **Fully and Semi-Automated Forces (Friendly and Enemy),**

Algorithmic representation of complex human behavior (e.g., from individual crew war-fighting to decision making at upper echelons) is at the center of intelligent systems design necessary for large simulations. Advances in this area are required to create distributed ‘forces” for joint task force/operations.

3) **ReusableTerrain and Environmental Data Bases.**

Data bases needed to construct the synthetic environments of ADS range from topography through complex weather models. These tend to be very large data bases. Collection, storage and retrieval, and updating continue to be issues of particular interest to DOD, and not necessarily just for simulation. Work needs to continue, especially for rapid data base generation.

4) **Verification, Validation and Accreditation (VV&A).**

Techniques routinely used for VV&A of single models or simulations face new challenges in a multi-source, highly interactive, internetted M&S environment where complex software modules are required to interoperate. New techniques of VV&A are likely required.

5) **Modeling and Simulation Construction Support Tools.**

Efficient software production environments unique to modeling and simulation are lacking in DOD. Domain specific tools should be developed.

In addition to these areas, the DOD should initiate work in the following new areas:

1) **Virtual Simulation Support for the Individual Combatant,**

Individuals play significant roles on the battlefield. Simulation technology must be developed to project individuals in realistic ways.

2) **Combining Some Live - Constructive - Virtual Simulation Interactions,**

The three classes of simulations often differ in granularity or resolution, time, and purpose. Seamless interoperation requires new development and experimentation.

3) **Simulation Support Tools for Logistics Medical. Maintenance. and Other Support Functions,**

These are complex and critical, yet often ignored, areas of combat operations. DOD needs to make a special effort to develop ADS components for these areas.

FINDINGS FROM TECHNOLOGY ASSESSMENT

- Commercial products and services will provide most hardware and networking capabilities
- Factor of ten price performance improvements every 2 to 5 years
- DOD investment required

5000.1 Not Compatible With Commercial Opportunity.

21. Video Tape: E&S 4000 Example of Terrain Data Progress

The video tape presented here an example of the rapid progress in advanced technology.

The procedure used to create this realistic battlefield environment begins with taking photo imagery from overhead collectors and laminating it to a pliable surface.

Features which sit on the surface of the terrain and which are important to military operations are then given 3-dimensional form. These might include buildings, bridges, utility poles, etc.

Finally, the topographic data base is merged with the image to create the contour of the location. Military operations commence.

The technique employed here allowed the development of the pictures which you see to be produced with about 4 man-weeks of effort over a 2 week period using a processor which costs about $1 million. We expect today's million dollar processor to be available in 3-5 years for $100,000 dollars.

- VIDEO TAPE-

E & S 4000
EXAMPLE OF TERRAIN DATA PROGRESS

22. Outline

We now transition to the second half of the briefing and address the opportunities arising from an experimental approach.

OUTLINE

- Definitions
- Historical and current examples and status
- Technology Assessment

- Opportunities & Vision
- Experimental Approach
- Recommendations

23. OPPORTUNITY

The opportunity available today is an unusual one. We have a situation where warfighters at various levels of command have developed the confidence to use advanced distributed simulation technologies to improve training and readiness, and take these to the limit in situations where human life is at stake.

The acquisition community has not yet developed the same confidence to use ADS technologies throughout the full range of the systems concept-through-fielding cycle. The acquisition community uses single simulation methods in piece-meal fashion. The assessment of the Task Force is that ADS technology is at hand and can provide the means to make substantial improvements in acquisition. The Task Force has already recommended that the DOD seize this opportunity since the evidence in this area is conclusive.

Because the warfighters will use and expand ADS applications and technologies on their own, the acquisition community should take advantage of this set of developments. The war-fighters' environment can be used on an end-to-end basis through the development cycle to develop the confidence to move from one state of development to another from what is learned through this interaction.

The current development system executed under 5000.1 allows for time compression and transitions from earlier to later steps when there is sufficient confidence to move ahead. The environment which the warfighters will be using can provide that confidence for the developer.

With today's technology, the DOD has demonstrated substantial utilization of modeling and simulation in a wide range of applications from detailed engineering design, prototyping and especially training. We have networked together existing tank, helicopter and other simulators geographically separated, and have demonstrated limited but useful combined arms exercises.

Under the Army's Advanced Distributed Simulation Technology (ADST) contract there are several dozen task orders developing new ADS capabilities. The ADST is also being used to perform evaluations between different land combat vehicles such as foreign and U.S. tanks.

More extensive employment of simulation to rapidly prototype systems is to be expected. An example is the Light Contingency Vehicle (LCV) program about to be started as a joint DARPA/Army/USMC initiative.

As described in the sister DSB Task Force report on Engineering in the Manufacturing Process, the employment of modeling and simulation can eventually tie the virtual battle to the factory floor. That linkage is not here today but evolving tools should permit much greater front-end requirements analysis, engineering trade-offs, system functional performance analysis, manufacturing process design and eventually unit processes modeling and analysis.

These new tools should increase confidence in the acquisition process, speed up the process, and reduce costs because of reduced engineering changes later in the development and manufacturing phases.

OPPORTUNITY

- Warfighters have developed the **confidence to use ADS** technologies to push training and readiness to war time limits . . . . **where human life is at stake**

- Acquisition community **has not yet developed the confidence** to use ADS technologies throughout the full range of a system's concept-to-fielding cycle

The opportunity is at hand for the acquisition community to take full advantage of ADS throughout the development cycle within the warfighter's environment

24. VISION

Having stated earlier that ADS technology is available and will have a substantial impact on readiness and training, the Task Force recommends the following be considered as a vision for the Department of Defense.

It recommends that DOD should have a near-term objective of applying ADS technologies and methodologies to leverage the elements of what we have already demonstrated to be successful at our training ranges. It should do this to all elements of our combat forces, their full supporting infrastructure, and make these part of normal training and readiness exercises. The further goal is that this would lead to more frequent and realistic training and ultimately to rehearsal within the short time-lines of crises and contingencies.

We recommend that DOD consider this to be a set of near-term objectives. It is feasible and affordable. Undertaking and implementing such a course of action will create a substantial **SYNTHETIC WARTIME ENVIRONMENT** is this that we recommend be applied by the acquisition community, along with the war-fighter in his training, to revolutionize the process by which requirements, development and acquisition are conducted. It is recommended that this application, and the changes that result from it, should be considered as changing the process from within.

Returning to the issue of readiness and training, we see a world situation with greater and greater uncertainty as far as the scenarios which might emerge and the need for military operations. In the past, we could prepare for a seeming worse case involving multiple campaigns in a global war environment against a monolithic enemy, the Soviet Union and its Allies. With the dissolution of the Soviet Union and the fragmentation of its empire (both internal and external), the so called lesser included cases now become the dominant cases. Unfortunately, where the Soviet Union was predictable in many respects-particularly in material development, doctrine, and force concepts-the regional instabilities which now exist and others which might exist in the future have a much more uncertain character. We know much less about the countries, their forces, equipment, concepts and the quality of their training and leadership.

The ClNCs and the Services have a great challenge before them in being able to plan and prepare to fight against a host of uncertain enemies in circumstances very likely to involve coalition forces. The ability to rehearse on short time lines will be crucial to managing crises and dealing with combat situations in the future.

The same ability, though, will create environments which can be used to advantage in requirements and development activities. These very environments can be used to examine new concepts, new hardware, adaptations of older hardware and assessing utility in both predictable and much more uncertain circumstances.

The basic ingredients do not change. It is necessary in both training and readiness and in establishing requirements and conducting development that we do it in circumstances which involve capable, opposing forces, all the environments we expect to see in combat circumstances and the ability to objectively evaluate the outcome. Since ADS can enhance the ability to do this over a wider range of circumstances that can be afforded with the live mode only, development should be enriched by the interaction.

What is suggested is a major, possibly revolutionary, change.

Up until late in the 1960s, training in the Services consisted of scripted field exercises resembling that of the 1988 REFORGER, or range-firing events involving live ordnance. Mediocre performances of our forces in Southeast Asia, however, prompted a search for better training techniques. By the end of the 1970s, all services had adopted a form of training termed “tactical engagement simulation” (TES), in which units in training are pitted against a capable opponent in free maneuver, weapon effects during encounters are simulated as realistically as safety will allow, the events are recorded, and a careful after action review follows to assure internalization of the training lessons. Facilities for TES require ample maneuver room, so that their most advanced versions are to be found in the Southwestern USA - Fallon NAS, Nellis AFB, Fort Irwin, Twenty-Nine Palms, etc.

Commanders of US forces during DESERT STORM have attributed the performance of our forces there to the transformation of their training wrought by TES, and especially its manifestation in SW USA. ADS offers the prospect of expanding and elevating these successes to encompass joint training and operational rehearsal, together with theater infrastructure. Moreover, since ADS records the behavior of warfighters under stress, in realistic battle scenarios, it can furnish data for improving models and simulations of all types. Most importantly, the synthetic battlefields of ADS can provide a warrior-comprehensible proving round for innovative doctrine, tactical concepts, and advanced applications of technology.

It is important to note that modern TES facilities resemble (in fact, were derived from) those used by the Test and Evaluation agencies for operational tests and experiments.

We believe that DOD should act to extend ADS to requirements development and refinement, to exploration of systems concepts and configurations, to evaluations of military worth, to materiel test and evaluation - even to manufacturing. The impact, we hold, is bound to be profound: new efficiencies of time and money in DOD acquisition.

VISION

We believe the following should be a near-term DOD objective and that it is feasible and affordable with current technology to:

- **Exploit and integrate** ADS technologies and methodologies to **leverage** the elements of our successful experience with training ranges to all **elements of combat forces,** and their full **supporting infrastructure** as a part of normal training and **readiness exercises**
- Accomplish much more **frequent and realistic** training and **rehearsal** inside crisis/contingency timelines
- Reflect the benefits of this **synthetic "wartime" environment** and activities to revolutionize the requirements development and acquisition process from within

25. DEMONSTRATIONS: OBJECTIVES

The Task Force recommends an experimental approach as the best method to seize the opportunity presented by ADS.

Rather than formulate exactly how far ADS technologies might take readiness and training and the requirements prototyping process and describing the innovative steps along the way, the Task Force believes that it is more prudent to engage the innovative spirits of the watfighters and the developers. We therefore recommend that a series of experiments and demonstrations be conducted to essentially enlighten, educate, and create demand.

We recommend that these experiments and demonstrations be conducted in a manner to 1) create a demanding war-fighting customer; 2) create the circumstances to envision how the requirements, prototyping and development process can be transformed from within, and 3) create a working relationship between the war-fighter and the developer.

We recommend that this be done with existing capabilities in an evolutionary manner building on new technology when it becomes available.

We recommend, therefore, a series of demonstrations with three primary objectives. They are:

1. To demonstrate to warfighters what can be done with ADS technology thus enabling exercises which will extend the utility. This community has long recognized and adopted ADS for limited purposes and will quickly adapt new capabilities to their needs, given a chance to try them out.

2. To demonstrate the power of ADS-based approaches in transforming the processes of combat development, system development and test and evaluation. Each of these portions of acquisition has used simulation to one level or another but no acquisition program has further utilized ADS to integrate all three in an end-to-end way. Combat development as used here includes developing requirements and developing and assessing tactics and doctrine associated with new or old concepts. Systems development typically begins with relatively simple levels of simulation to assess first order tradeoffs, growing with the system maturation to detailed, high fidelity simulations (e.g., dome simulators, system integration labs). T&E, rather than operating on the end product of system development, would participate in simulation and associated physical experiments and trials, at every stage of combat and system development.

3. To demonstrate the power of the ADS environment to serve the needs of both warfighters and acquisition community. Further to demonstrate that common usage enriches the use for both. For example, developers can work in a wartime environment well validated by war-fighters. War-fighters can experiment early on with new concepts under consideration by developers.

DEMONSTRATIONS: OBJECTIVES

Structure and execute a series of ADS experiments and demonstrations to:

- ☑ Create and educate a demanding warfighting customer
- ☑ Transform the requirements - prototyping process from within
- ☑ Bring warfighter and developer together

Grow on existing nets . . . .
Expand and extend as needed . . . .
Modular approach . . .
Leverage what we have. . .

26. DEMONSTRATION AND EXPERIMENT SUMMARY

The Task Force devised 12 experiments/demonstrations that develop and illustrate the use of available or emerging ADS technologies to address identified needs to:

- Improve readiness;
- Boost ability to conduct joint operations;
- Provide better, more focused support to acquisition--requirements, assessment, risk reduction, testing; and
- Provide more responsive reserve forces combat units.

The Task Force believes that any or all of these are well within the state of the art of available technology. Given funding, any or all could be accomplished within two years.

While the Task Force game focused attention to a set of 12 demonstrations, only involved users in the operational training and acquisition communities can define the most effective ways to use ADS technologies to improve and transform training and acquisition.

A key objective of these demonstrations is to attract operator involvement in focusing ADS technology on the right set of problems. The most important purpose of these demonstrations is to educate potential users regarding the potential of these technologies thereby producing demanding operational and acquisition customers.

The Task Force accomplished **a** first order technical feasibility evaluation for each suggested demonstration/ experiment. Further work to match available technology to the candidate demonstrations should be the task of a technical working group directed by DDR&E and CJCS and led by DARPA in cooperation with the JCS and Services.

Once technical feasibility is further defined and validated, JCS J-7, supported by DDR&E in cooperation with the Services, should confirm the operational value of candidate demonstrations.

While it is not necessary to identify a specific CINC customer before getting underway with work on the demonstration, a CINC should be identified for involvement before the actual individual demonstration.

Finally, a series of demonstrations would be brought together in support of appropriate Service and joint exercises.

See Appendix B.

DEMONSTRATION AND EXPERIMENT SUMMARY (AND EXPECTATIONS)

Serve demanding warfighting customers:

1. JTF operations in SW USA *(improve joint capability)*
2. Interactive exercise at home stations *(previously impractical)*
3. Integrated National Guard Brigade Training *(previously impractical)*
4. CINC wargaming networking *(new capabilities from existing systems)*

Transform the acquisition process:

5. Shared situational awareness in close combat *(evaluate concepts/technology)*
6. Theater air and missile defense *(evaluate new concepts/technology)*
7. Suppressing critical mobile targets *(new capability from old systems)*
8. Networked battle games *(new capability from commercial systems)*
9. Battlefield visibility *(evaluate new concepts/technology)*

Derive combined effects:

10. Network training and test ranges *(previously impractical)*
11. Realistic electronic combat test and training *(previously impractical)*
12. Improving warfighter C4I interface *(new capabilities from existing systems)*

27. SOUTHWEST UNITED STATES TEST AND TRAINING RANGE COMPLEX (SWUSTTRC) (INTEGRATED TEST AND TRAINING RANGES, FACILITIES, AND ACTIVITIES)

One of the most important sets of capabilities to leverage involves what is available in the way of capabilities in the Southwest United States. These should be networked along with forces which are distributed throughout the U.S. In the near future, virtually all of the regional commanders and chiefs will be based in the U.S. as will be virtually all the forces except for some forward deployed naval forces and some forward deployed air and POMCUS. Thus the internal U.S. network should make available all the capabilities that exist in the Southwest for use in training exercises and development.

This is not to imply that the only portion of the country that might be employed for such activities would be in the Southwest U.S. The big advantage of ADS technology is that it allows forces and developers to operate at their home bases through a network that reaches to appropriate facilities for either their training or development activities.

The Department of Defense (DoD) has invested billions of dollars in developing training and test ranges in the southwestern United States. The ranges are under the control of the Army, Navy, Marines or Air Force. Each with its own mission, projects, and workload. Interoperation is limited to only a few centers.

The Chairman of the Joint Chiefs of Staff (CJCS) has recommended that the Defense Science Board (DSB) attempt to quantify the potential for modeling and simulation (M&S) to improve Defense acquisition, military training, and joint operations through the use of training and test range interconnectivity and virtual reality modeling methodologies. The SWUSTTRC provides an area to meet the CJCS' request. The instrumented ranges in the SWUSTTRC will exploit the convergence of three types of tactical engagement simulation: virtual, constructive, and live range exercises.

Proposed exercises in SWUSTTRC might focus on: a special operations exercise at the National Training Center (NTC); actual use of systems such as Joint Direct Attack Missile (JDAM) and Tomahawk Land Attack Missile (TLAM) for deep precision strike; virtual employment of JDAM, TLAM, and other systems; Third Fleet exercise (off the Coast of California) with a T&E operation; electronic warfare exercise at China Lake; UAVs with various sensors; a forced entry exercise at Camp Pendleton; all supported by actual and virtual aircraft from such places as Fallon, Nellis, Miramar, and possibly aircraft carriers. This is strictly an example to communicate intent. The user communities would design such an exercise to meet their needs.

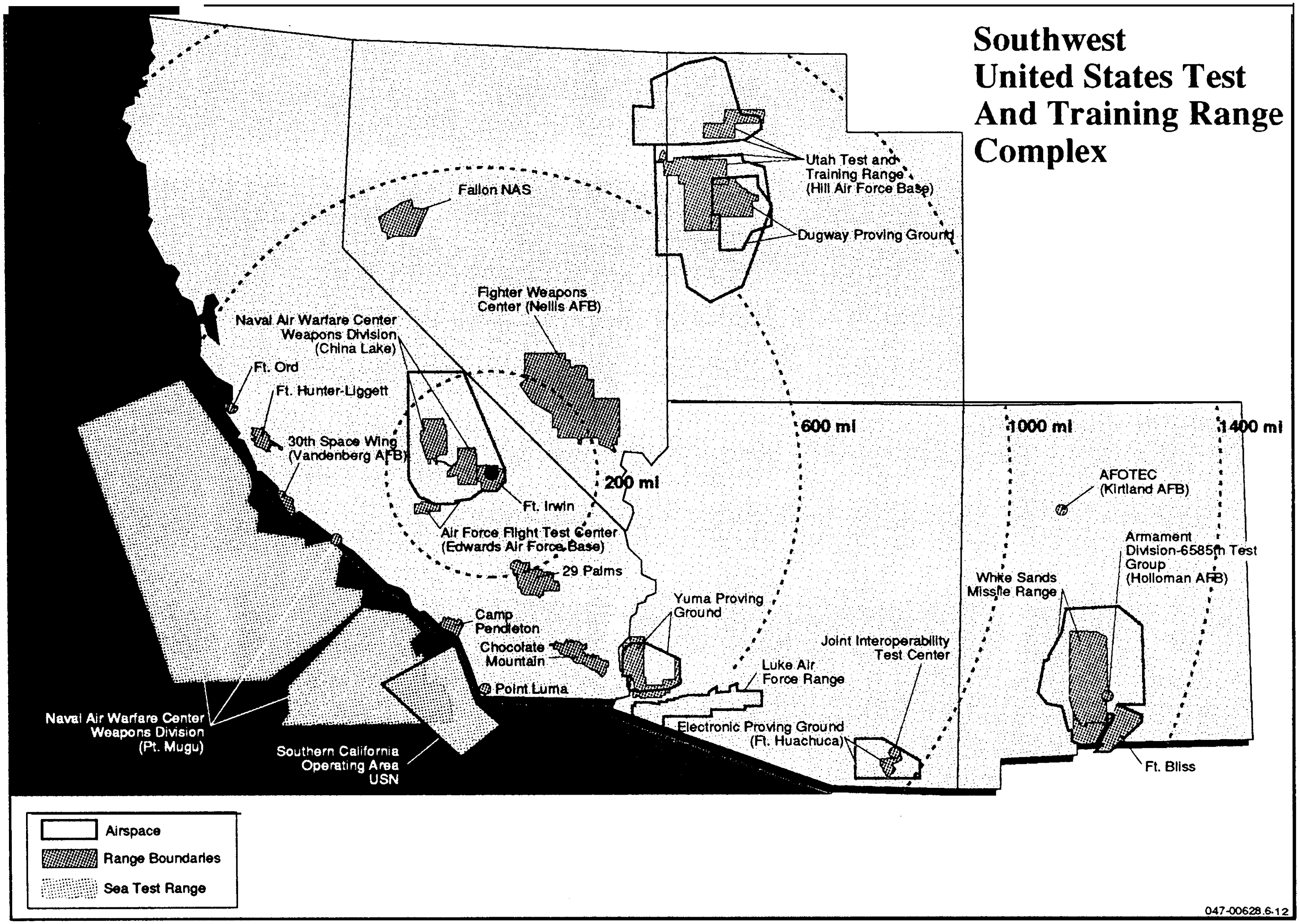
The DSB makes the recommendation for an exercise in the SWUSTTRC to leverage the country's continuing investment in its test and training ranges. Networking these ranges together and adding both constructive and virtual simulation will improve joint readiness; concept development; and weapons simulation and test validity. Further, the experiment will create an environment for regular CINC evaluation, understanding, and integration of emerging capabilities.

Leveraging these investments for early and continual involvement of user communities in systems development from concept through deployment will vastly improve the acquisition process. A combination of such exercises with simulation will create opportunities for realistic joint training at the Joint Task Force level, exercising contingency capabilities, and introducing new capabilities into contingency planning.

With the increased emphasis for joint operations, more efficient employment of the existing ranges is required.

A key element in connecting these various centers is a network which builds upon existing connectivities such as the Air Force (DATS) adding programmed (and funded) connectiveness such as T&E Range Internetting System (TERIS) and Defense Simulation Internet (DSI), with additional connectivities not yet identified to establish a complete network for interoperability for test and training evolutions such a powerful tool provides easy acces to the numerous elements which should participate in life cycle decisions as well as significantly improve force readiness through greater combat realism.

The next two charts elaborate on two of the twelve suggested demonstrations. A complete description of all twelve demonstrations is contained in the Appendix.


Southwest
United States Test
And Training Range
Complex
Utah Test and
Training Range
(Hill Air Force Base)
Dugway Proving Ground
Fallon NAS
Fighter Weapons
Center (Nellis AFB)
Naval Air Warfare Center
Weapons Division
(China Lake)
Ft. Ord
Ft. Hunter-Liggett
30th Space Wing
(Vandenberg AFB)
Ft. Irwin
Air Force Flight Test Center
(Edwards Air Force Base)
200 mi
600 mi
1000 mi
1400 mi
29 Palms
Camp
Pendleton
Chocolate
Mountain
Point Luma
Yuma Proving
Ground
Luke Air
Force Range
Joint Interoperability
Test Center
Electronic Proving Ground
(Ft. Huachuca)
AFOTEC
(Kirtland AFB)
Armament
Division-6585th Test
Group
(Holloman AFB)
White Sands
Missile Range
Ft. Bliss
Naval Air Warfare Center
Weapons Division
(Pt. Mugu)
Southern California
Operating Area
USN
Airspace
Range Boundaries
Sea Test Range
047-00628.6-12

28. DEMO #1: JOINT TASK FORCE OPERATIONS IN SW USA

<u>OBJECTIVE</u>. Exercise Joint Task Force battle staffs in the Southwestern United States.

<u>WHY?</u> Our forces can do fragmented pieces of Joint Task Force (JTF) campaign planning and training today. But, they are unable to involve multi-service planners and operators often enough, or on the scale requisite, for foreseeable contingency operations. Instead, they have relied upon ad hoc arrangements to meet contingencies as they develop. For the future, they need arrangements that facilitate repetitive, short notice JTF exercises in which each JTF commander and his staff can be exercised in campaign planning, task order preparation, and communication and evaluation of results.

<u>WHAT</u>? This demonstration will network existing SW USA training and testing facilities of the several services under a JTF to provide for regular battle staff training in a realistic environment. It seeks to add virtual and constructive simulation to that live simulation, enhancing its effectiveness without interfering with attainment of its objectives.

<u>BENEFITS</u>. The new technology will enable:

- Extending the perception of the units actually present of adjacent and supporting friendly units,and of an opposing force deployed in depth, represented by live and virtual elements.

- Incorporating national and theater intelligence inputs, to be evaluated against outputs in targets for prosecution, or in post-strike assessment.

- Providing for attacking targets geographically off-set from where they were located by intelligence, so that striking units can exercise against the most advantageous available simulation of target and defenses.

DEMO #1: JOINT TASK FORCE OPERATIONS IN SW USA

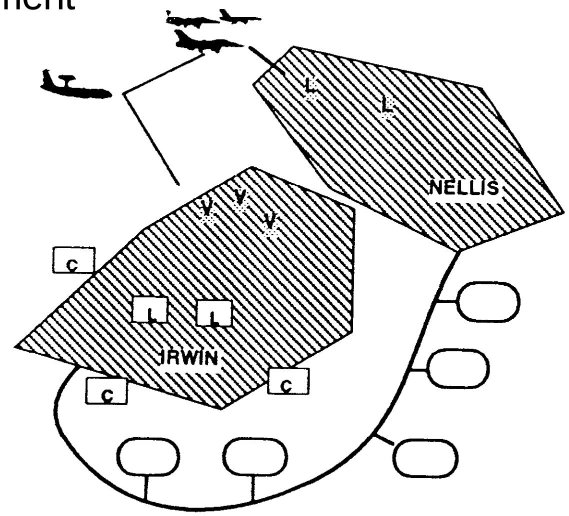
- ***Objective:***

  Conduct series of Advanced Technology Demonstrations of joint training overlayed on Service training at SW USA live ranges. In 1994:

  - **Internet** the several Service ranges and a JTF [CVBG/Air Wing/Army Division/Marine MEB] supported by the Joint Warfare Center
  - Without interfering with Service training, provide a **synthetic environment** in which units actually present perceive themselves operating in the context of the entire JTF and against an enemy force represented by live, constructive, and virtual elements
  - **Exercise NTM** and theater broad-area sensors [live and virtual]; evaluate from target prosecution and post-strike damage assessment

- ***Why?***
  - Short-notice JTF exercises
  - C4I interoperability to execute-level

- ***Benefit:***
  - Demonstrably **ready joint forces**
  - **Reusable,** up-gradable simulation components
  - **Data** for M&S improvements



29. DEMO #6: THEATER AIR AND MISSILE DEFENSE

Elements of the Simulation

Elements of the simulation must include the Patriot and THAAD systems, including all sensor systems, missile weapons, and control and communication stations, and linkages between these systems. Also included could be simulations of other systems that might provide important sensor warning indications, such as DSP/FEWS, JSTARS, ASARS, and National Technical Means. Sea-based defensive missile systems should be included. Existing and new communications and data links between all these systems and the theater commanders, including appropriate security considerations, should be evaluated. New threats, including low-observable missiles at all altitude, need to be considered, as well as wide range of terrain and sea-based simulation scenarios. jamming and disruptive actions by other threat forces, as well as terrorist activities, should also be considered for simulation.

Structure of the Experiment

A major element of the experiment involves finding the targets, launching a coordinated attack,and killing the incoming missile targets, with damage assessment. Timelines for decision making and systems automated responses must be measured and evaluated, indicating the ability of being able to use collateral data from other sources within time-decision windows. A broad matrix of sensor and intelligence inputs should be evaluated by human operators in a mission context, against a wide range of threat types and attack densities and severity (numbers, cleverness of tactics, threat use of intelligence, etc.). The impact of new technologies, such as new sensors, improved processing for accuracy and speed, and graphical displays for decision making should be assessed. Also, the capability to accept intelligence inputs from other human operators such as pilots, ground observers, etc. as cueing inputs for the missile defense system should be considered, as well as the needed interfaces with other theater Service mission elements. Simulated coordination with mission planning of other air and ground forces, to understand the impact of both the incoming threats and the TMD response on other military actions, must be accomplished to determine the “real-time” requirements.

Reauirements of the Experiment

Simulations exist for most system elements needed. They need to be made DIS-connectable and the real-time capabilities and needs of each must be assessed. Early experiments by industry and government indicate that it takes about six months and $4-5 million to complete a complex (DIS) simulation with validated results (DARPA estimates, IDA experiments) and the availability of Service operators motivated to help is ESSENTIAL. Ground truth (terrain, any historical data) and reasonably accurate simulations (matching the complexity of the DIS-protocol data stream--a missile must be complex and a satellite which passes only a few data signals doesn’t) are needed. Preliminary simulations of new capabilities (Secure C41 links between systems, new sensors, interfaces with command authorities, etc.) can be made available fairly quickly for assessment in an operational context.

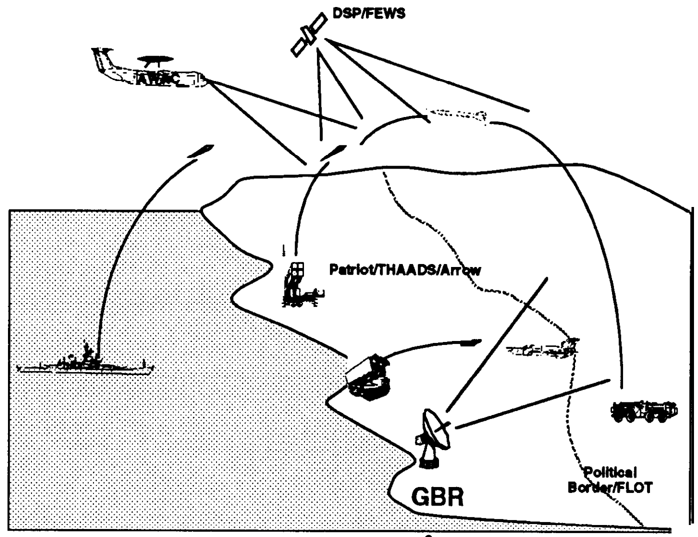
Desired Outcomes

The impact of new ideas for interoperability, finding and destroying incoming missile threats and assessing damage must be measured in realistic DIS scenarios with real operators using real sensor and intelligence data. Operators need to have the best data and conclusions available to allow rapid decisions in the battle context. Measured bounds on the best and worse sensor data, assessment predictions, timelines for prosecution will allow future planners to consider ideas like requesting data from AWACS and JSTARS and other aircraft in real time, directing attacks at launch points, etc. Given the power of DIS, operators will come up with methods, tactics and requirements of new data and capabilities that will greatly assist efforts to address Theater Missile Defense.

The Air Defense Mission has forever included elements from all the services deployed to the Theatre of Operations. The control of the air has been, because of technology and budget limitation, largely procedural and slow to adapt to the advancing threat. As a result of Desert Storm the psychological impact of the Tactical Ballistic Missile has been brought to sharp focus. The Department of Defense has pressed forward to develop THAADS/FEWS, Improved Patriot, SM-2 Block 4, and other systems to protect allied nations and combatants from this threat more effectively. Many, if not all of these new systems, have produced

DEMO #6: THEATER AIR AND MISSILE DEFENSE

- ***Objective:***
  - Provide early operator involvement in **evaluation and integration** of evolving theater air and missile defense capacity
  - Develop simulation and virtual environment to ensure **timely validation** of doctrine and tactics for early contingency deployment
- ***Why?***
  - Large investment in relevant simulation capability (examples include SDC, TACSSF, Falcon, etc.)
  - Current capability is not being employed to provide current and evolving joint operational systems evaluation
  - Multiple systems alternatives, PATRIOT III and ERINT, THAAD, AEGIS, ARROW, GBR can be evaluated and architectures assessed for varying operational scenarios
- ***Benefit:***
  - Provide **early** assessment and developer feedback of **operational utility**
  - Assure development of doctrine, tactics and procedures to **match** evolving operational capability
  - **Integrate** theater defense simulation into test training, rehearsal with CINC battle staffs
  - Opportunity **to use prototype weapons for contingency operations**



29. DEMO #6: THEATER AIR AND MISSILE DEFENSE (Cont'd)

deliverable simulation hardware for the purpose of evaluating single service concepts, requirements and costs. The DSB recommends that these devices be connected to the DSI network and be wargamed with other Air Defense Assets currently available to the ClNCs and Services.

It is a fortuitous accident that the timing of the ATBM System Component's demval matches the readiness of ADS. We are now ready to examine, with the user, alternative requirement sets, force employment, and development options prior to commitment to EMD.

This demonstration is a trail blazer for many similar exercises underway. It involves air, sea and land forces; the SDIO; the CINCS; and the development community. Furthermore, it leverages government owned simulators that are readily interfaced to the ADS.

Answers of importance can be achieved with virtual simulation with little other than the interface development required.

THAADS = Theatre High Act Air Defense System (USARMY)

FEWS = Follow-on Early Warning System (USAIRFORCE)

SMZ = Standard Missile **2** (USNAVY)

ATBM = Anti Tactical Ballistic Missile

ADS = Advanced Distributed System

EMD = Engineering Manufacturing Development

DEMO #6: THEATER AIR AND MISSILE DEFENSE

- ***Objective:***
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  - Large investment in relevant simulation capability (examples include SDC, TACSSF, Falcon, etc.)
  - Current capability is not being employed to provide current and evolving joint operational systems evaluation
  - Multiple systems alternatives, PATRIOT Ill and ERINT, THAAD, AEGIS, ARROW, GBR can be evaluated and architectures assessed for varying operational scenarios
- ***Benefit:***
  - Provide **early** assessment and developer feedback of **operational utility**
  - Assure development of doctrine, tactics and procedures to **match** evolving operational capability
  - **Integrate** theater defense simulation into test training, rehearsal with CINC battle staffs
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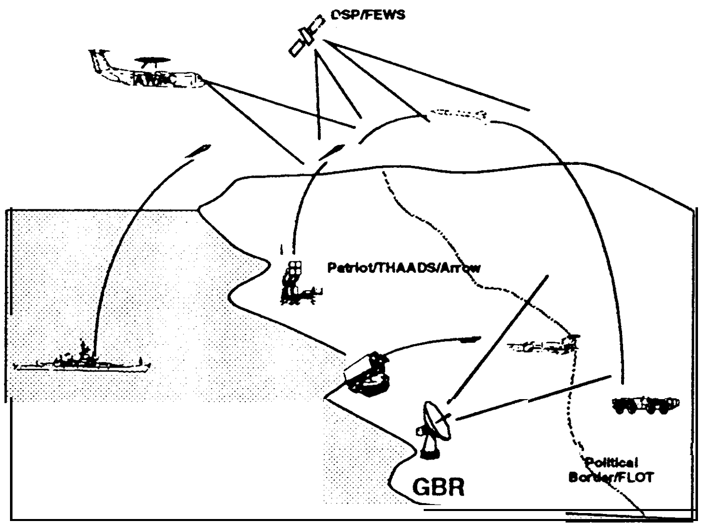


30. RECOMMENDATION #1

In conclusion, the Task Force makes five recommendations.

This first recommendation goes to the heart of realizing the potential and benefits of ADS technology. The DOD ***must*** establish, promulgate and enforce standards and protocols which allow for two things:

- Interoperability within the DOD environment, and
- Interoperability in the commercial environment.

Anything less will limit ADS benefits and increase costs.

RECOMMENDATIONS

1. The DDR&E and T&E communities and the Services should:

   - Establish and enforce standards and protocols to facilitate the interoperability and reusability of ADS tools and technologies in training and materiel development

   - incorporate standards and protocols into all developments and procurements which contribute to enhancing the ADS environment and its use

   - Fully internet training ranges, test facilities, laboratories, service schools, and industry, and make them DIS compatible

31. RECOMMENDATION #2

The passage of the Defense Reorganization Act of 1986 (Goldwater-Nichols Act) reassigned to the Chairman, Joint Chiefs of Staff, responsibilities for joint training that in the National Security Act of 1947 had been assigned to the Joint Chiefs themselves. The current statue (Title 10 USC, Ch 5, Section 153) charges the Chairman in these terms:

> "The Chairman of the Joint Chiefs of Staff shall be responsible for. . .
>
> (A) Developing doctrine for the joint employment of the armed forces.
>
> (B) Formulating policies for the joint training of the armed forces.
>
> (C) Formulating policies for coordinating the military education and training of members of the armed forces."

JCS Pub 0-2**, Unified Action Armed Forces (UNAAF),** 1 December 1986, (p. 1-12), states that:

> ". . .The Chairman will:
>
> (16) . . . recommend a budget proposal for activities of each unified and specified command. Activities for which funding may be requested in such a proposal include:
>
> (a) Joint exercises.
>
> (b) Force training.
>
> (c) Contingencies.
>
> (d) Selected operations. . .
>
> (18) Develop and establish doctrine for all aspects of the joint employment of the armed forces.
>
> (19) Formulate policies for the joint training in the armed forces.
>
> (20) Formulate policies for coordinating the military education and training of the members of the armed forces."

Unlike his fellow members of the Joint Chiefs of Staff, the Chairman has no robust acquisition team to advise him on technological opportunities that might underwrite new policies, or enhance standing policies. Yet ADS could be of material assistance in joint training. Hence, we hold that CJCS should form a partnership with the DDR&E to enable a range of policies for joint training not now on the books (e.g., JTF Operations in SW USA) and create and sustain a theater of war environment for joint training and to improve the development process from within.

The J-7, as the designated agent of the CJCS should work with DARPA and elements of the Acquisition Community to actualize demonstrations to create demanding customers among the CINCs. The J-7 should be the support activity which provides the CINCs with what they need. A Letter of Agreement has been executed between the CJCS and the DDR&E (see attached) agreeing to be the sponsors for this activity.

RECOMMENDATIONS (Cont'd)

2. The CJCS and DDR&E should:

- Establish a constantly available ADS **joint warfare environment** and build on existing technology by:
  - Publishing implementing policy
  - Empowering the J-7, DARPA, DTE, DISA, and others within the next two years to carry out experiments and demonstrations
  - Using the experiments and demonstations to create a **theater of war environment** t0 foster conceptual and technological innovation to interconnect forces and their infrastructure and National Technical Means (NTM)

DONE

MEMORANDUM OF AGREEMENT
BETWEEN THE
VICE CHAIRMAN OF THE JOINT CHIEFS OF STAFF AND THE
DIRECTOR FOR DEFENSE RESEARCH AND ENGINEERING
ON
ADVANCED DISTRIBUTED SIMULATION APPLICATIONS

1. The technologies associated with Advanced Distributed Simulations. (ADS) provide exceptional potential to improve our joint warfighting capabilities. ADS applications have been demonstrated to be useful for training commanders and battle staffs (e.g., WPC, BCTP), for simulating close combat (e.g., SIMNET-T, SIMNET-D), and for joint training in large scale, world-wide exercises (e.g., Ulchi Focus Lens 92). Future applications can markedly improve requirements definition and refinement; research, development, and acquisition; test and evaluation; doctrine and tactics development and assessment; planning and Courses of Action assessment; training, exercises and military education. Both prudence and economy dictate that the United States capitalize on ADS to leverage its defense investments, and to assure national security in an uncertain world, despite diminished budgets.

2. To date, ADS requirements have been primarily shaped by DARPA and its service users. As ADS begins to move out of research and development, it requires joint direction and sponsorship to focus and leverage its potential. To that end, the undersigned shall, commencing in FY 1993, formulate and pursue, with the Services and Commanders-in-Chief of the unified and specified commands, demonstration programs to find practical ways in which ADS can improve development and assessment of joint doctrine, plans, operations, training and education, and to exploit ADS for support of research, development, tests and evaluations throughout the Department of Defense.

SIGNED:

DAVID E. JEREMIAH
Vice Chairman,
of the
Joint Chiefs of Staff
19 AUG 1992

VICTOR H. REIS
Director for
Defense Research
and Engineering
19 AUG 1992

32. RECOMMENDATION #3

The DSB recommends that the DDR&E, with the Services, conduct a series of experiments and demonstrations described in detail in Appendix B. They are designed to leverage current assets and to apply ADS technology. Based on the experience gained over the next years with these experiments and demonstrations, the operators and the acquisition community will be able to judge where and how ADS technology can best be applied to serve them in the future.

The experiments define a context in which to refine military hardware concepts and requirements. Alternative designs for high risk hardware elements can be simulated by a virtual prototype and evaluated in the context of relevant parts of a synthetic battlefield. Simulations of the user's interface to the proposed hardware can be put in the hands of the warfighters early. The interaction dimension aids the war-fighter in scrutinizing the system with respect to doctrine and tactics. For example, given a simulation of an unmanned aerial vehicle and a synthetic/live battlefield on which to exercise it, warfighters determined that the requirement for a 'dash mode' was unnecessary. It is expected that refinements of both concept and hardware design can be reflected in the simulations at relatively low cost in both time and dollars.

These experiments and demonstrations should be sufficient to determine whether ADS technology shortens development time. Two reasons for expecting a decrease in development time are: 1) fast turnaround time for the refinement of concept and design; and 2) quantitative data on the performance of a proposed system on the synthetic battlefield. Currently, development time is longer than it need be because the DOD and Services require believable assessments of low risk. Quantitative data -- from a validated simulation -- will provide the measurements that permit confident risk assessment leading to earlier decisions. Also, reliable measurements that lead to the elimination of costly, incremental requirements, can lead to a technically less demanding and faster development of real prototypes.

The experiments and demonstrations will demonstrate the potential for ADS to enhance training and increase force readiness. The joint warfare environment permits rapid reconfiguration of training assets. Thus they can be rapidly tailored to simulate a particular contingency. In a contingency using the synthetic battlefield - a commander can explore the usefulness of prototypes and brassboards. Also the commander can exercise his staff's ability to create ad hoc solutions to problems he poses.

Together, the experiments and demonstrations, will illustrate the flexibility of the synthetic battlefield environment, serve to show the warfighter the potential for ADS and be the basis for ongoing investments in the application of ADS technology.

RECOMMENDATIONS (Cont'd)

3. The DDR&E, the T&E community, and the Services, should carry out a series of experiments and demonstrations using the ADS environment to:

- Refine military hardware concepts and requirements
- Explore opportunities to shorten development time
- Provide opportunities to take to war: brassboards, prototypes and ad hoc solutions within crisis and contingency timelines

33. RECOMMENDATION #4

These recommendations are described in detail in Appendix A.

RECOMMENDATIONS (Cont'd)

4. DDR&E should give priority to investing in the following DOD required ADS tools and technologies:
   - Maturation areas:
     - Simulation scalability (virtual)
     - Fully and semi-automated forces (friendly and enemy)
     - Reusable terrain and environmental data bases
     - Modeling and Simulation construction support tools
     - Verification, Validation and Accreditation
   - Void Areas:
     - Virtual simulation support for the individual combatant
     - Combining some live - constructive - virtual simulation interactions
     - Simulation support tools for logistics, medical, maintenance and other support functions

34. RECOMMENDATION #5

The acquisition of ADS technology should be exempted from the 5000.1 paper.

The DOD acquisition process has to be modified to take rapid advantage of the two to five year product cycle of enabling commercial products into M&S (and other) applications. There should be a technology turnover insertion clause in those DOD contracts which rely heavily on using off the shelf commercial products such as workstations, computer image generators, and data base management systems, just to name a few.

The efficient and cost-effective development of ADS must more intimately involve the ultimate user community from CINCS on down. There should be a user "pull" for ADS but they must be convinced of its utility, flexibility, and validity.

A series of 6.3A - like advanced technology demonstrations (such as those planned in the DDR&E Thrust 2 Precision Strike and War Breaker and the Light Contingency Vehicle [LCV] in Thrust 5) could be a very useful technique for merging the best attributes of M&S, prototyping and real field trials.

To reduce the internal bureaucratic processes it is suggested that full 5000.1 procedures be modified to assist the rapid development of 6.3A - like ATDs and their enabling tools.

Once more confidence is gained by the acquisition and test and evaluation communities in M&S there should be new procedures implemented which both speed up acquisitions and reduce cost/risk in DOD programs. Richer employment of M&S in each step of the acquisition milestone process could yield significant dividends.

All development contracts which have models or hardware modules as deliverables, should require these to be interfaced with appropriate standards and protocols to the DSI network.

RECOMMENDATIONS (Cont'd)

5. The Deputy Secretary of Defense should:

- Direct procurement of ADS technologies in a modular / evolving process which closely couples users and developers and **exempts** ADS from the 5000.1 process

- Select and execute several acquisition programs which will employ an ADS environment for all steps from concept to fielding to **build confidence** in modification of 5000.1 to include **fast track and step skipping** measures

APPENDIX A:

REPORT OF THE SUBPANEL ON

TECHNOLOGY ASSESSMENT AND FORECAST

TABLE OF CONTENTS

LIST OF FIGURES

I. INTRODUCTION[1]

Background

A subpanel of the Defense Science Board (DSB) Panel on Simulation, Readiness and Prototyping was formed to perform an assessment and forecast of the enabling technologies for modeling and simulation (M&S). The DSB members of this subpanel were Ivan Sutherland, Sam Tennant, and Don Latham. They were supported by Col Jack Thorpe from the Defense Advanced Research Projects Agency (DARPA), James Chung, a DARPA consultant, and several Service and Department of Defense (DOD) agency personnel.

Scope

In performing the assessment and forecast, the subpanel received inputs from a wide spectrum of government laboratories, Agencies, and commercial industry. These industrial inputs ranged from those companies engaged in DoD-funded M&S programs to commercial companies engaged in developing devices and software for applications as diverse as the use of simulation in commercials and full-length feature films. Important inputs were provided by the telecommunications industry, the computer industry, and DARPA on the development and forecast of computer networks and global wideband networks.

Organization

The material in this appendix is organized as follows. The relevant technologies are first identified according to their commercially and DOD-driven components (Section II), with the commercially driven ones next being discussed in more detail (Sections III and IV). The appendix then turns its primary focus to the DOD-driven technologies. Following a general discussion of the relevancy of these technologies (Section V), three particularly important areas-architecture, synthetic environments, and computer generated forces-are discussed (Sections VI-VIII). One particular DOD technology application area deserving further discussion, engineering design and manufacturing, is presented next (Section IX), followed by consideration of the subject of verification, validation, and accreditation, which should pertain to all the technology applications (Section X). Three sections then form the

1 This report was prepared during the two-week DSB Summer Study based on briefing materials, discussions with experts, and best judgment. A much more thorough technology assessment should be performed on a continuing basis.

concluding portion of the appendix. They treat (Sections XI-XIII, respectively) the overall assessment of the DOD-driven technologies, investment considerations for these technologies, and overall observations and recommendations.

II. APPROACH TO TECHNOLOGY ASSESSMENT AND FORECAST

The broadening scope of applications for modeling and simulation in the DOD is driving a widening range of technologies. The scope of applications for modeling and simulation include requirements definition and analysis, virtual prototyping, program planning, engineering design and manufacturing, test and evaluation, and training and readiness.

The approach taken by the subpanel was to develop a hierarchy of enabling technologies and to segregate them as to primarily commercial driven and those that are primarily DOD driven. Some enabling technology areas fell into a middle area in which both commercial industry and DOD were investing. What was of primary interest was meeting two objectives: (1) correctly identifying the key enabling technology areas which DOD must follow and invest in, and (2) assessing the maturity and estimating the on-going investment activity for each technology area.

Figure 1 displays the "M&S Enabling Technology Hierarchy," showing four levels from enabling fundamental technologies in Level 0 to application technologies at Level 3. To achieve Level 1 component technologies, one must employ the Level 0 technologies and others; similarly at Level 2, one must employ Level 0 and Level 1 capabilities to reach Level 2 systems. Twelve technology areas are shown to the right of the vertical line at each level. Those technology areas in the center of the chart, such as high performance computing systems, are of interest to both commercial and DOD users. There is some DOD investment in these middle of the road technologies but not much on the scale of global investment.

Figure 2, "DOD-driven M&S Technology Examples," displays some examples of the technologies which go into making up the 12 DoD-driven technologies; clearly there many other technologies in these areas as well.

Figure 1
M&S ENABLING TECHNOLOGY HIERARCHY

← COMMERCIAL DRIVEN —— DOD DRIVEN →

LEVEL 4 - OBJECTIVE: INTEGRATED SYNTHETIC ENVIRONMENT AND M&S TOOLS FOR

- REQUIREMENTS DEFINITION
- PROTOTYPING
- PROGRAM PLANNING
- DESIGN & MANUFACTURING
- TRAINING & READINESS
- TEST & EVALUATION

LEVEL 3 - SIMULATION APPLICATION TECHNOLOGIES

- MANUFACTURING PROCESS SIMULATIONS
- ENGINEERING DESIGN MODELS & SIMULATIONS
- MANNED SIMULATORS
- STOCHASTIC WARGAMING SIMULATIONS
- SAFOR

LEVEL 2 - ENABLING SYSTEM TECHNOLOGIES

- MICROCOMPUTER SYSTEMS
- TELECOM/ WIDE AREA NETWORKS
- HUMAN-COMPUTER INTERFACES
- CIG SYSTEMS
- HIGH PERFORMANCE COMPUTING SYSTEMS
- INSTRUMENTED RANGE SYSTEMS
- DoD DATA BASES
- DoD PROTOCOLS/ STANDARDS/ SECURITY

LEVEL 1 - ENABLING COMPONENT TECHNOLOGIES

- MEMORY
- MASS STORAGE
- DISPLAYS
- LOCAL AREA NETWORK
- MICRO-PROCESSORS
- DBMS
- A/D/A CONVERTERS
- M&S CONSTRUCTION TOOLS
- INSTRUMENTATION

LEVEL 0 - ENABLING FUNDAMENTAL TECHNOLOGIES

- FIBER OPTIC COMMUNICATIONS
- INTEGRATED CIRCUITS
- SOFTWARE ENGINEERING TOOLS
- HUMAN BEHAVIOR REPRESENTATION MODELS
- ENVIRONMENTAL REPRESENTATION MODELS

Figure 2
DoD-DRIVEN M&S TECHNOLOGY EXAMPLES

LEVEL 3

MANUFACTURING PROCESS SIMULATIONS
- FMS/Automated Assembly
- Material Mgmt - JIT Inventory
- CIM Process Planning

ENGINEERING DESIGN MODELS & SIMULATIONS
- Structural/Fluid Dynamics
- Finite Element Analysis
- Stability and Control

MANNED SIMULATORS
- Training
- Combat Dev
- Human Factors

STOCHASTIC WARGAMING SIMULATIONS
- Training
- Combat Dev
- Historical Rev.

SAFOR
- Training
- Combat Dev

LEVEL 2

INSTRUMENTED RANGE SYSTEMS
- Subsistent TES Systems
- Embedded Systems
- Virtual/Real World Interfaces

DoD DATA BASES
- Terrain/Cartographic
- Dictionaries/Directories
- Intelligence Data
- Electronic Combat Data

DoD PROTOCOLS/STANDARDS/ SECURITY
- Protocol Standards & Interoperability
- Multilevel Security
- End-To-End Encryption Technologies

LEVEL 1

M&S CONSTRUCTION TOOLS
- Terrain Data Base Generation
- Real-time Applications
- Protocols/Interfaces
- Validation & Verification

INSTRUMENTATION
- Position/Orientation Transducers
- Velocity/Acceleration Sensors
- Actuators and Advanced Displays
- GPS/Digital Comm Links

LEVEL 0

HUMAN BEHAVIOR REPRESENTATION MODELS
- Cognitive Behavior Research
- Military Doctrine Research
- Human Factors Research

ENVIRONMENTAL REPRESENTATION MODELS
- Weather/Atmospheric Effects
- Electromagnetic Interactions
- Dynamic Terrain Representation

III. COMMERCIAL-DRIVEN TECHNOLOGY FORECAST[2]

In many areas of computer development the commercial sector outspends DOD by a great deal. The pace of progress in these areas is little affected by DOD actions. Moreover, DOD must draw on commercial developments in these areas or simply be left behind.

The pace of commercial development in computing is awesome, without precedent. High volume manufacturers of personal computers have come to expect a new generation of equipment nearly every year, and consider two-year old equipment to be obsolete. It is common for the new generation to provide twice the capability of the previous generation, rendering earlier equipment obsolete. This pace of development is in striking contrast to the pace of mature commercial areas like the automobile and aircraft industries, where change is relatively slow. Whereas a ten-year old automobile or airplane, well maintained, performs nearly as well as a new one, a ten-year old computer is an antique.

DOD's laborious procurement process is ill-matched to the pace of commercial computer development. Any procurement that takes more than two years runs the risk of buying obsolete computer equipment. Others in DOD are concerned about this mismatch and so we will not belabor it here (instead, see Section IV, "Technology Turnover"). Our task, rather, is to indicate the direction and probable result of the commercial developments on which DOD may be able to draw.

The following sections discuss commercial-driven technologies that the DOD needs to keep abreast of and incorporate into its procurement process on a timely basis.

Integrated Circuit Technology

The fuel for this rapid pace of development is the digital integrated circuit (IC). No other technology in history, save the atomic weapon, has provided the sudden enormous increase in capability offered by integrated circuits. From circuits with a few tens of transistors, we have now progressed to commercial exploitation of single chips with multiple millions of transistors. Moreover, this millionfold increase in complexity has been augmented by an increase in speed as well. This development provides the base on which modem electronics is founded.

2 **A** more extensive version of this section is in preparation by James Chung, a consultant for DARPA, and to be published by the Institute for Defense Analyses (IDA) in the fall of 1992.

Developments in integrated circuits have involved making smaller transistors and wires so that more of them may be fabricated on each single chip of silicon. To do so has required great capital expenditures for very precise manufacturing equipment whose development and purchase ultimately limits the pace for the entire industry.

We expect the pace of integrated circuit development to continue at least to the end of the century. There is some reason to believe that it will slow down then because the physics of transistors as we now understand it requires them to be bigger than a certain minimum size. Smaller transistors will not work for a variety of reasons such as materials break down from excessive electric fields and inadequate numbers of impurity atoms to provide uniform electrical behavior and so forth. We cannot now see how to reduce the scale beyond what our present rate of development will reach at the end of this century. Development beyond that level seems to require a new invention that may not be forthcoming. In spite of this limitation the developments of the 1990s will be impressive.

Other Technologies: Magnetics and Communications

Rotating magnetic storage technology has kept up a similar pace. Secondary storage is almost uniformly now provided by magnetic disk memories. The amount of storage, the size and weight, and the cost of these systems have all improved remarkably in the past. We believe that these developments will continue during the forthcoming decade.

Should magnetic storage technology fail to keep up, it may simply be replaced. Remember when the main memories of computers also used to be magnetic? We still retain hints of the "core" memories of yesteryear in our language, but core has come to mean "central' instead of referring to the magnetic cores from which memories were once made. Magnetic technology for central memory was replaced by electrostatic memory on silicon chips. Magnetic memory for secondary storage will either keep up or be similarly replaced.

The most important communication development, of course, is fiber optics. By sending light through a transparent wire, the electrical interference of long conductors is avoided. This provides not only high speed but greater reliability. Unfortunately, simplicity of interconnection that was possible with copper wire is lost, but the loss is not great because at the communication speeds involved, even wires have to be connected with great attention to geometric detail.

DOD'S Proper Role

Although DOD's investment in these technologies is small compared to industry, DOD can nevertheless play an important role. Industrial developments must, because of commercial necessity, focus on subjects with near-term commercial returns. DOD investments on longer-term subjects and on items without commercial counterparts are therefore unique and important. DOD must invest in technologies of unique defense interest. For example, radiation hardening is of no commercial interest. We believe DOD should invest in emerging technologies whose exploitation is further in the future than industry can justify now. DOD's traditional role in advanced research has provided many developments now being exploited commercially. We encourage DOD to maintain an active role in the technologies of the future.

Our Predictions

We have divided our view of the world into three levels (see Figure 3, "Commercial-driven Technology Forecast"). In level 0 we include fundamental technology with widespread applicability. Fiber optics, integrated circuits, and software are the three technologies on which we focus. We see continuing rapid development in integrated circuits through the end of the century. We see less rapid development in fundamental fiber optic technology, but improvements in cost and ease of use will continue. Software will continue to be a problem because it is here that all of system complexity hides. The software problem will continue to be the problem of exactly what does the system do.

In level 1 we have grouped the component technologies. Extrapolating from the past rapid developments we see DRAM (Dynamics Random Access Memory) costs for memory descending nearly a hundredfold. Mass storage sizes and costs will also continue to develop. Raw computing power, also fueled by the integrated circuit developments, will improve nearly a hundredfold.

In level 2 we have put the system implications of these developments. The amount of computing power available per dollar by the end of the century appears to be enormous by any standard.

The Affect of Technology on Simulation

The most interesting part of this development is shown in the top line of our chart in Figure 3, "Commercial-driven Technology Forecast." It asks, how many computers will there be in the world good enough to do a simulation network (SIMNET) simulation? One station for such a simulation today takes computing equipment valued at tens, if not hundreds, of thousands of dollars. There are, in the entire world, only a few thousand such systems, and battlefield simulation is relatively rare.

What is striking is that by the end of the century we can expect tens of millions of computers with that same level of capability. They will be used in homes for entertainment, and in

Figure 3
COMMERCIAL-DRIVEN TECHNOLOGY FORECAST

	1992 A.D.	2000 A.D.	IMPLICATIONS
#SIMULATION CAPABLE PLATFORMS	~1000	-10 Million	• *Equipment suitable for real-time simulation will be widely available.*
LEVEL 2 - SYSTEM			
• Microcomputer Systems	- 100 SPECmarks $20K	• 1000- 10,000 SPECmarks $20K	- *Increased computing power will bring the cost of today 's simulation systems into a range accessible to private citizens for entertainment uses*
• Telecom/WAN	- DSI (T1 - 1.5 mbps)	• DISN SONET/ATM (OC-48 2.4 gbps)	
- Man-System Interfaces	Direct view & projection CRT	• Head mounted displays? Direct view & projection CRT	
• CIG System	- $100K per channel 100K polys/sec 100M pix/sec	• 10M polys/sec, 2B pix/sec	
• High Performance Computer Systems	- MPP, Vector 20 GFLGPS, $20M	• MPP >1 teraflop, $1M	
LEVEL 1 - COMPONENT			
• Memory	• 4M DRAM, ($5.00 per mbit)	• 256M DRAM ($0.08 per mbit)	- *The advent of multi-chip modules will permit components in 2000 A.D. to have the capability of today's systems.*
• Mass Storage	• 100 mbits/sq in (mag) 300 mbits/sq in (M-O)	• 1000 mbits/sq in (mag) 16 gbits/sq in (M-O)	
• Displays	• CRT/STN/TFT	• Lower costs CRT/STN/TFT	
- LAN	• FDDI (100 mbps)	• ATM/SONET (OC-48 2.4 gbps)	
• Microprocessors	• 100 MIPS	- 1,000-10,000 MIPS	
• DBMS	• Relational, GIS, object oriented	• Intelligent & integrated DBMS (Rel/GIS/object-oriented)	
• A/D/A Converters	• 16-bit flash conversion	• Higher resolution/speed lower cost	
LEVEL 0 - FUNDAMENTAL			
• Fiber Optic Media	• Multi-mode silica fiber (0.2 db/km loss @ 1.55 pm)	- Same	- *The rapid increase in integrated circuit performance may taper off after the year 2000 A.D. because of physical limits to transistor functions.*
• Integrated Circuits	• 3 M transistors CMOS VLSI 0.7 mm line widths	• 10 M transistors CMOS VLSI 0.25 mm line-widths	
• Software Dev Tools	-OK	- Better	

!

the workplace to prepare presentation materials, to edit video, and to operate technical and economic models. They will be used by a large fraction of the population.

In this environment rich with computing, DOD'S own simulators will play a small part. DOD's behavior must be to aid and encourage the emerging market for simulation materials. DOD can support the industrial developments in important ways. DOD's data bases, particularly of geography, will play an important role. DOD could sponsor and even endorse commercial versions of its own gaming systems to provide a realistic base for training of the civilian population. DOD can expect to enlist a generation of soldiers already familiar with simulation. We will have to be good indeed to capture and retain their interest.

DOD'S Role in the Long-Term Future

DOD has traditionally played a role in future technologies. This role reaches beyond the time horizon of interest to industry to technologies expected to become valuable in 5 to 10 years. Its best flowering was in the aircraft industry where DOD developments in aircraft design, fundamental research, and manufacturing technique (especially numeric control of machine tools), were outstandingly valuable not only to DOD but to our civil aviation business. In the computer area DOD's inputs have been equally valuable. DARPA's work in the ARPAnet and on-line use of computing has proven exceedingly valuable. We encourage a continuation of this role.

This longer-term role is valuable for two reasons. First, it helps to channel industrial developments into areas of interest to DOD. Remember that DOD has always been a major consumer of very large scale computing for weapons design, cryptography, and simulation. DARPA has provided and is still providing support in advanced super computing. These efforts lead to systems that help DOD directly. It is vital, the argument goes, that we have available to us the best computing machines in the world.

The second value of a continued DOD role in longer-term developments is to renew the intellectual storehouse of our nation. Industry takes ideas from demonstrations to products, but someone has to make the demonstrations. DOD plays a very valuable role in taking ideas from dreams to demonstrations. DOD's work in high powered lasers, for example, is beginning to see commercial application. In the fields relevant to simulation, DOD's continued efforts in better display technology, better software technique, and particularly in validation, will be essential. Advanced DOD efforts establish the state of the computing art.

IV. TECHNOLOGY TURNOVER

Based on the rather detailed survey of the commercially driven technologies (Chung's report referenced in Section III), we found that the relative performance price of these technologies was improving at a dramatic rate on two- to five-year cycles. In contrast, the ability of DOD to define and procure M&S systems appears to be on an 8- to 12-year cycle. Figure 4, "Technology Turnover," illustrates this issue with a few of the commercial technology cycle data points plotted.

Not plotted but at the heart of the technology turnover issue are the software and data base developments required to create a specified DOD M&S capability. For example, the current U.S. Air Force program to develop a sophisticated Special Operations Forces (SOF) Aircrew Training System (SOFATS) must (1) design and develop 7 all new aircraft and aircrew simulators; (2) develop the computer-based training packages for nearly 60 crewstations; and (3) construct worldwide topographic and electronic threat data bases and tie all that capability together with software tools to permit the creation of a real Mission Rehearsal package within 48 hours of notification. About 500,000 lines of Ada code will be required to implement SOFATS.

The SOFATS system is being designed to an open architecture and all the major hardware components are commercial-off-the-shelf so it should be possible to insert the system hardware with relative ease, given the budget to do so. The problem is that by the time the system is fully up and operating, the initial hardware decisions are more than five years old because of the multiyear front-end development cycle.

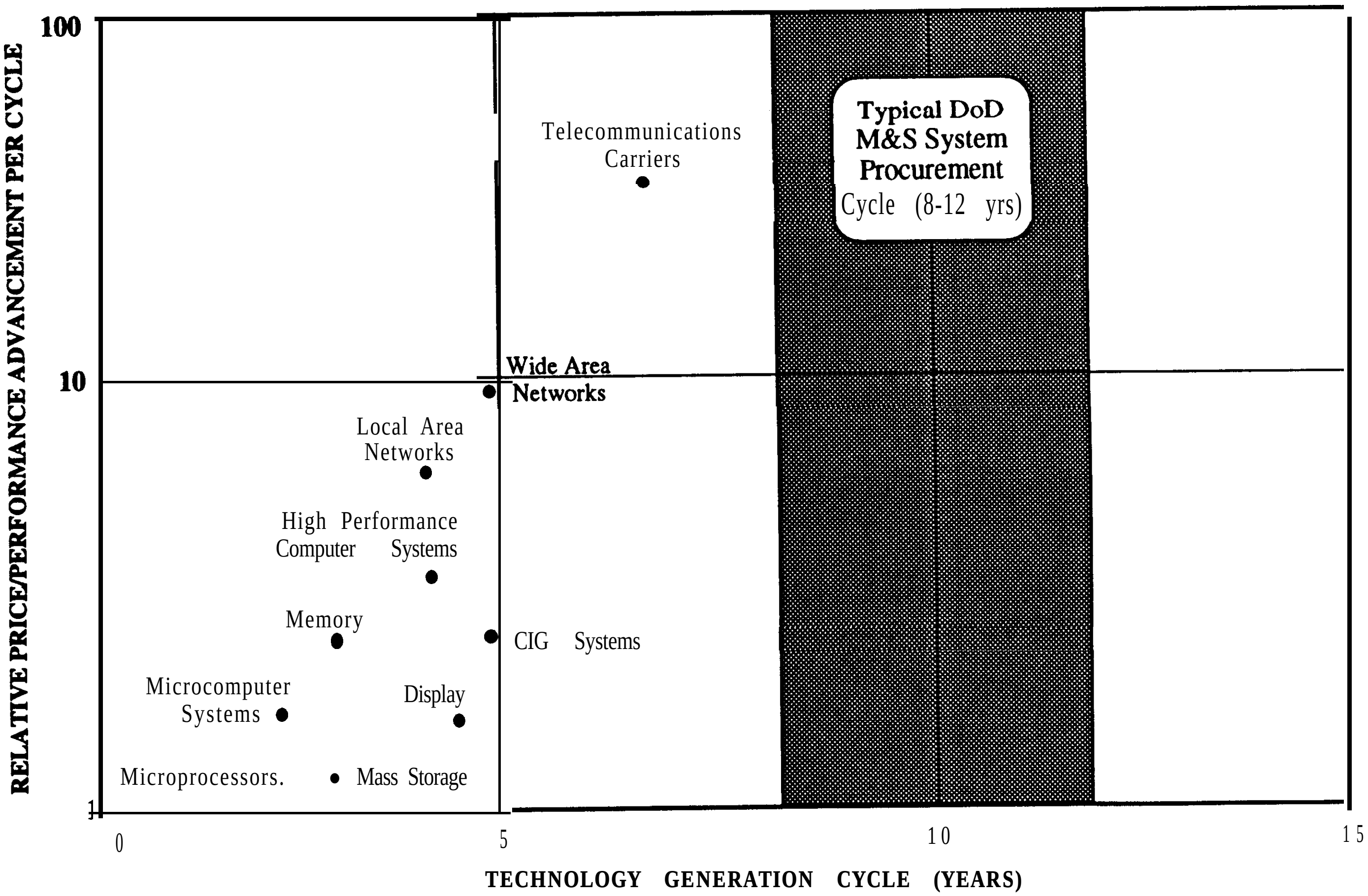
Major DOD M&S system contracts should be written to include a technology turnover clause. Such a clause can incentivize both the government and the contractor to seek new technology insertion as price performance permits. The government should want to spend less to get the latest technology and could afford a negotiated additional fee for rapid insertion of the latest technology. Typical value-added engineering clauses are common in most DOD contracts and should be part of any M&S contract.

Forward pricing on hardware items such as workstations can permit the latest technology insertion into the production system as long as great care is taken to ensure software portability.

Some technology will come to DOD essentially for free. For example, there is a need for multicasting network

Figure 4
TECHNOLOGY TURNOVER

Key Issue: Is there a way for DOD to take advantage of commercial enabling M&S technologies which advance on a 2-5 year cycle within an 8-12 year procurement cycle for DOD M&S systems?



capabilities in support of distributed networked simulation. The new ATM-based (Asynchronous Transfer Mode) networks will incorporate a multicast capability, meeting at the same time a commercial requirement for that unique capability.

In other commercially driven technology areas of significant interest to M&S, such as Computer Image Generators (CIGs), there is no requirement for DOD investment to develop new CIGs since new high performance generations are occurring on about a three- to-five year cycle or faster for workstation-based CIGs. For example, one CIG vendor has a product priced at $7,000 which is twice as powerful as an earlier product priced at $80,000 only five years before. Current high-end applications of CIGs (such as in SOFATS) are not yet utilizing all the power of the current commercial products.

In summary, technology turnover in some M&S applications is of real concern. DOD should take innovative contract approaches to ensure that new, lower cost, improved performance hardware is readily accessible and insertable.

V. RELEVANCY OF THE DOD-DRIVEN TECHNOLOGIES

For each of the planned applications of M&S in DOD an assessment was made as to the relevance (high, moderate, minimal) of the 12 technology areas to each application. Using this approach, we attempted to assess how well the technologies matched the applications and to identify technology gaps by noting which M&S applications were poorly supported by the 12 areas.

Figure 5, "Technology Relevancy," displays the results of the relevancy assessment. More "black" dots and "half-shaded' dots would be desired overall. However, it is primarily at Level 3 that increasing relevance should be expected and the results bear that out. This is a very subjective analysis and each dot could be argued one way or the other as to the most accurate representation of relevancy. The Engineering Design and Manufacturing area is in need of greater scrutiny as to specific enabling technologies at all levels. In the other M&S applications the 12 technologies appear to map reasonably well at this highly aggregated level.

Figure 5
Technology Relevancy

High Relevance ●
Moderate Relevance ◒
Minimal Relevance ○

APPLICATION UTILITY OF DOD DRIVEN TECHNOLOGIES

	Requirements Definition	Program Planning	Prototyping	Design/Manufacture	Test & Evaluation	Training/Readiness	Mission Planning/Review
Level 3 - Simulation Application Technoloaies							
Manufacturing Process Simulations	◒	●	●	●	○	○	○
Engineering Design Models and Simulations	●	◒	●	●	◒	○	○
Manned Simulators	◒	○	◒	○	◒	●	●
Stochastic Wargaming Simulations	●	○	○	◒	◒	●	◒
SAFOR	◒	◒	●	○	●	●	●
Level 2 - Enablina Svstem Technologies							
Instrumented Range Systems	○	○	◒	○	●	●	●
DOD Databases	◒	◒	◒	◒	●	●	◒
DOD Protocols/Standards/Security	◒	◒	◒	○		●	◒
Level 1 - Enabling Comoonent Technoloaies							
M&S Construction Tools	◒	○	●	○	●	●	◒
Instrumentation	◒	◒	●	○	●	●	●
Level 0 - Enablina Fundamental Technoloaies							
Human Behavior Representation Models	◒	◒	●	○	◒	○	●
Environmental Representation Models	◒	◒	○		●	●	●

Increasing Relevance ↑

VI. ARCHITECTURAL CHALLENGES IN DISTRIBUTED SIMULATION[3]

The implementation of appropriate protocols and standards is central to the effective realization of distributed simulation. However, issues of underlying structure should be dealt with first. This involves the higher level considerations of architecture in which the basic interfaces and fundamental services of distributed simulation are treated.

This section first reviews the demands placed upon architecture by the greatly increased scale anticipated for distributed simulation. Current architectural concepts and the need for their expansion are then discussed, followed by consideration of four key issues relating to this need for expansion. For each issue area, current capabilities and potential future technological directions are briefly reviewed. This section is summarized and concluded by presenting some general initiatives to advance the state of architectural development.

3 This chapter is based on material from the 1992 DARPA Information Science and Technology (ISAT) summer study on simulation technology. The chapter was written by Richard Ivanetich, a member of the ISAT summer study team.

Scalability

The ability to accommodate vast increases in scale is a fundamental challenge facing distributed simulation. This scalability may be characterized as having four dimensions:

(1) Cardinality: Number of objects in the simulation.

(2) Granularity: Fidelity and level of detail of objects and environment.

(3) Heterogeneity: Diversity of objects and environments.

(4) Timeliness: Promptness of constructing and using the simulation.

Examples of potential increases in scale are as follows:[4]

Cardinality . The number of objects, e.g., vehicles on the battlefield, will increase from the roughly 1,000 currently demonstrated in distributed simulation to 10,000- 100,000 in simulations used for the training of upper echelon commanders.

Granularity. Terrain descriptions will increase from the relatively broad granularity used today (e.g., 100 m resolution) to a much more refined level (e.g., 1 to 10 m resolution) to support such activities as mission rehearsal. Similarly, the

4 Section VIII, Application of Advanced Software Technology to Development of Computer Generated Forces, provides further discussion of these dimensions as they relate to Computer Generated Forces.

fidelity required of weapon system description models will increase as more emphasis is placed on the prototyping use of distributed simulation.

Heterogeneity. The diversity of the simulation applications will increase as the initial land battle orientation of distributed simulation is broadened to encompass several other aspects of warfare, including such fundamentally different types as undersea warfare.

Timeliness. Increased demand on timeliness will result as the application of distributed simulation to crises is considered. For example, creation of terrain databases, which now typically requires weeks or months, would be required in the space of a few days.

In short, if scalability is envisioned as a four-dimensional space, then current applications all cluster near the origin of the space. Future applications, however, will result in a "big bang" filling out a much greater volume of this space.

Current and Future Architectural Concepts

The ability to support this greatly expanded scale will not just happen. Simple extrapolations of current technical concepts and capabilities could become more and more difficult to implement as the scale grows, until finally a "complexity barrier" is reached. To deal with such increases in complexity, the proper structure and abstractions must first be put in place. That is the subject of architecture.

The current architecture for distributed simulation, as specified in the SIMNET program, requires all simulators to communicate with one another by exchanging a specified set of protocol data units (PDUs) that describe the changes in state of the weapon and support systems represented by the simulators. Each of the simulators contains a complete terrain database and a representation of all other weapon and support systems participating in the simulation. Thus, each simulator calculates its "view of the world' based on the PDUs received and its internally stored data. Furthermore, using its own system model and the incoming PDUs, each simulator calculates the effects on itself that the actions of other simulated weapon or support systems might have (e.g., the effects of a weapon being flied).

This relatively straightforward architectural concept has allowed for the successful implementation of SIMNET and its limited extension beyond the original land battle configuration. However, significant extension and modification to this architectural concept will most likely be required to accommodate the increases in scale noted above. For example, the proliferation of many new vehicle types could require greater emphasis on mechanisms to ensure configuration management in introducing and modifying weapon and support system representations; databases could become too large or calculations too computationally expensive to replicate them at every simulator; and the increase in the numbers of objects in a simulation could render it impractical to continue sending all PDUs to all simulators.

Four key issues pertinent to establishing an expanded architecture to accommodate large increases in scaling have been identified, each of which will be discussed in the sections below:

(1) Internal simulator architecture

(2) Inter-operability of simulators

(3) Simulation operating systems

(4) Communication architecture

The brief discussions that follow are not a comprehensive treatment of the subject of distributed simulation architecture. Rather, through consideration of four important issues, the intent of the discussion is to show that the subject of architecture is a rich and complex one that goes well beyond considerations centered upon protocol data units. Indeed, fundamental issues in computer science and in distributed computing in particular will have to be treated to define the architecture appropriately.

Internal Simulator Architecture

In general terms, the interfaces characterizing distributed simulation span three levels, as indicated in Figure 6, "Levels of Architecture." The highest level refers to the interaction between simulators and is characterized by the SIMNET or DIS protocols. The intermediate level pertains to the interfaces between the components of the simulators, which are notionally depicted in Figure 7, "Notional Simulator Component Architecture." The lowest level refers to the interfaces among those segments constituting the individual simulator components - e.g., the JMASS architecture can be used to describe the interrelationship between the segments constituting a system model.

Currently, definition of the components of a simulator and specification of the interfaces between these components have not been generally addressed, although there is ongoing work particularly regarding the definition of standards for the terrain databases that will be used in the simulators. This lack of a more complete specification of the simulator component architecture can lead to two problems:

(1) Redundant developmental efforts could be required because components developed for one simulator (e.g., an environmental model) would not be readily insertable into other simulators that require a similar component. In other words, lack of standardized interfaces could lead to proprietary solutions lacking in more general applicability. Furthermore, development of a new component for a second simulator could lead to inconsistencies (e.g., in describing dynamic environment effects) with respect to the first simulator.

Figure 6
LEVELS OF ARCHITECTURE

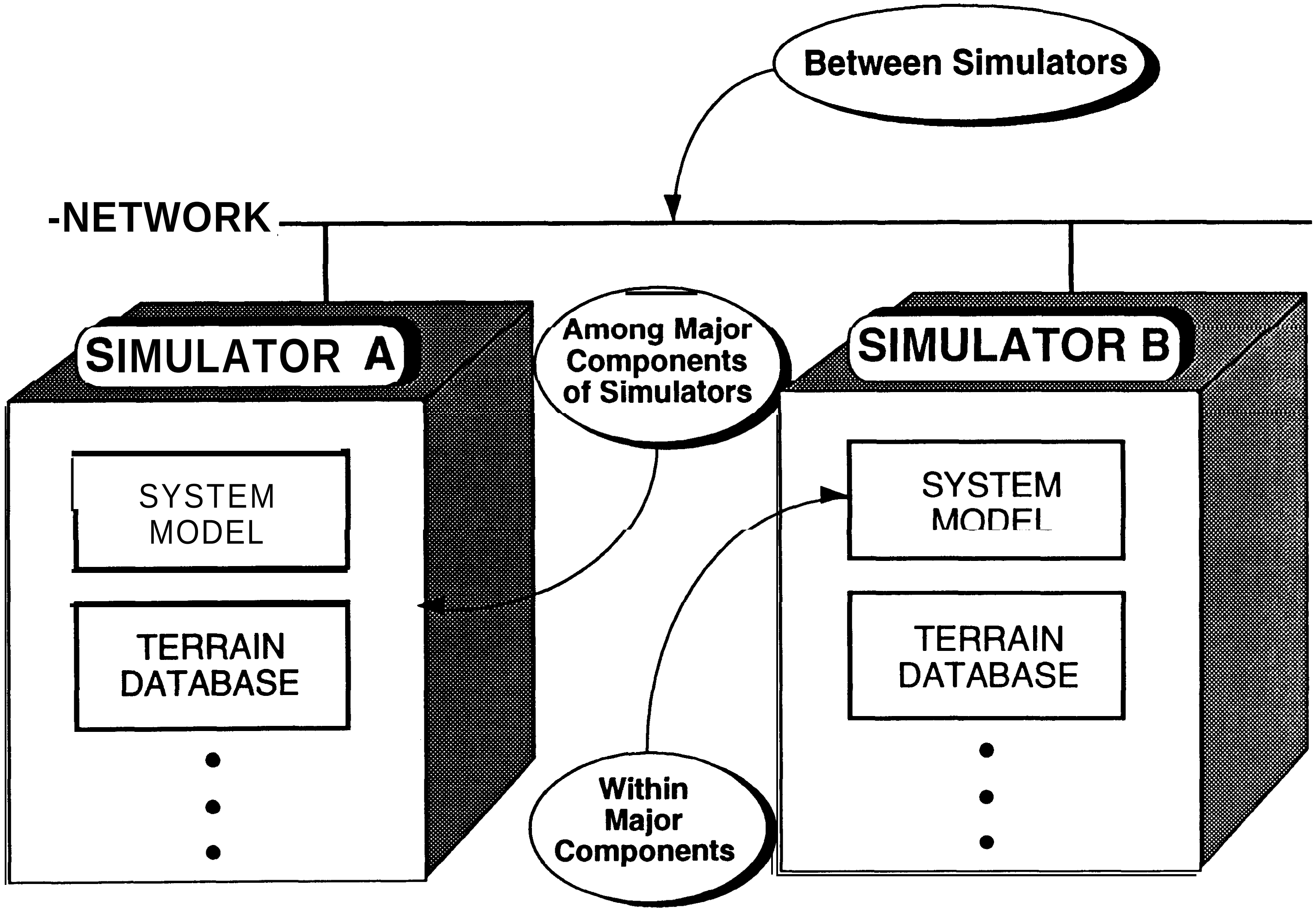
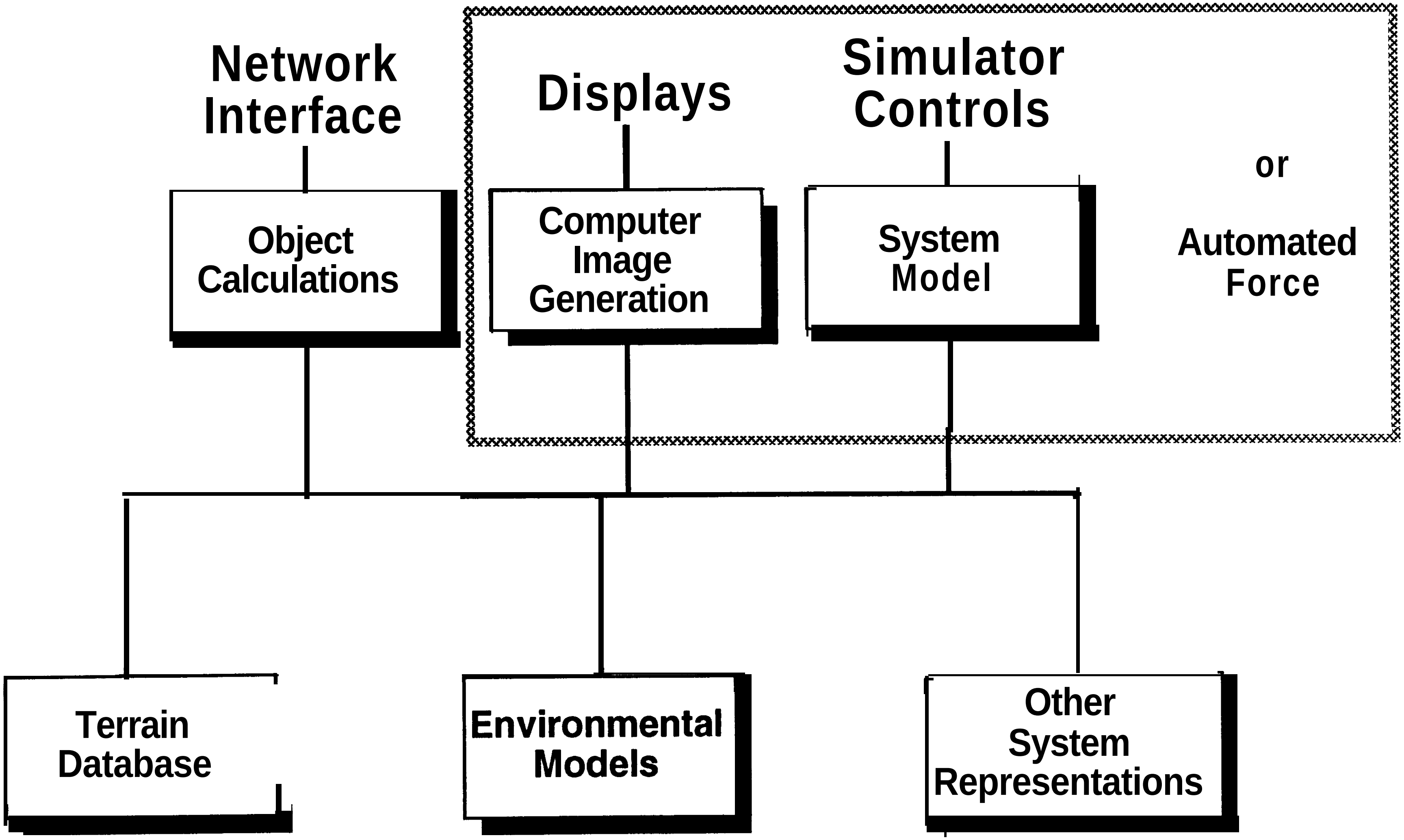


Figure 7
NOTIONAL SIMULATOR COMPONENT ARCHITECTURE



(2) Configuration management would also suffer. In particular, the component Other System Representations, in Figure 7, “Notional Simulator Component Architecture,” should be split out separately so that the representation of these systems can be easily updated as the description of such systems is changed, as they inevitably will in the evolution of systems and applications. (“Other” here refers to the other weapon and support systems with which a given system interacts.) If such representations cannot be easily updated, then the task of updating will become increasing complex as the number of systems represented in the simulation increases should not be a difficult technical task, but full specification of the appropriate interfaces and standards could well be a time-consuming effort.

Interoperability of Simulators

Not all simulators have been built to one set of interoperable specifications, nor will all be in the future. Yet it is often highly desirable to interconnect these simulators. Significant interconnections of this type are being carried out, as indicated, for example, by the War Breaker experiments presently being initiated (see Figure 8, “Intemetting Dissimilar Simulations”). However, the interconnections of dissimilar simulators are achieved by a “brute force” method of translating the state representation from one simulator to match a common one (the SIMNET or DIS protocol). While this approach can lead to interoperable simulators, it is often time consuming and costly[5]

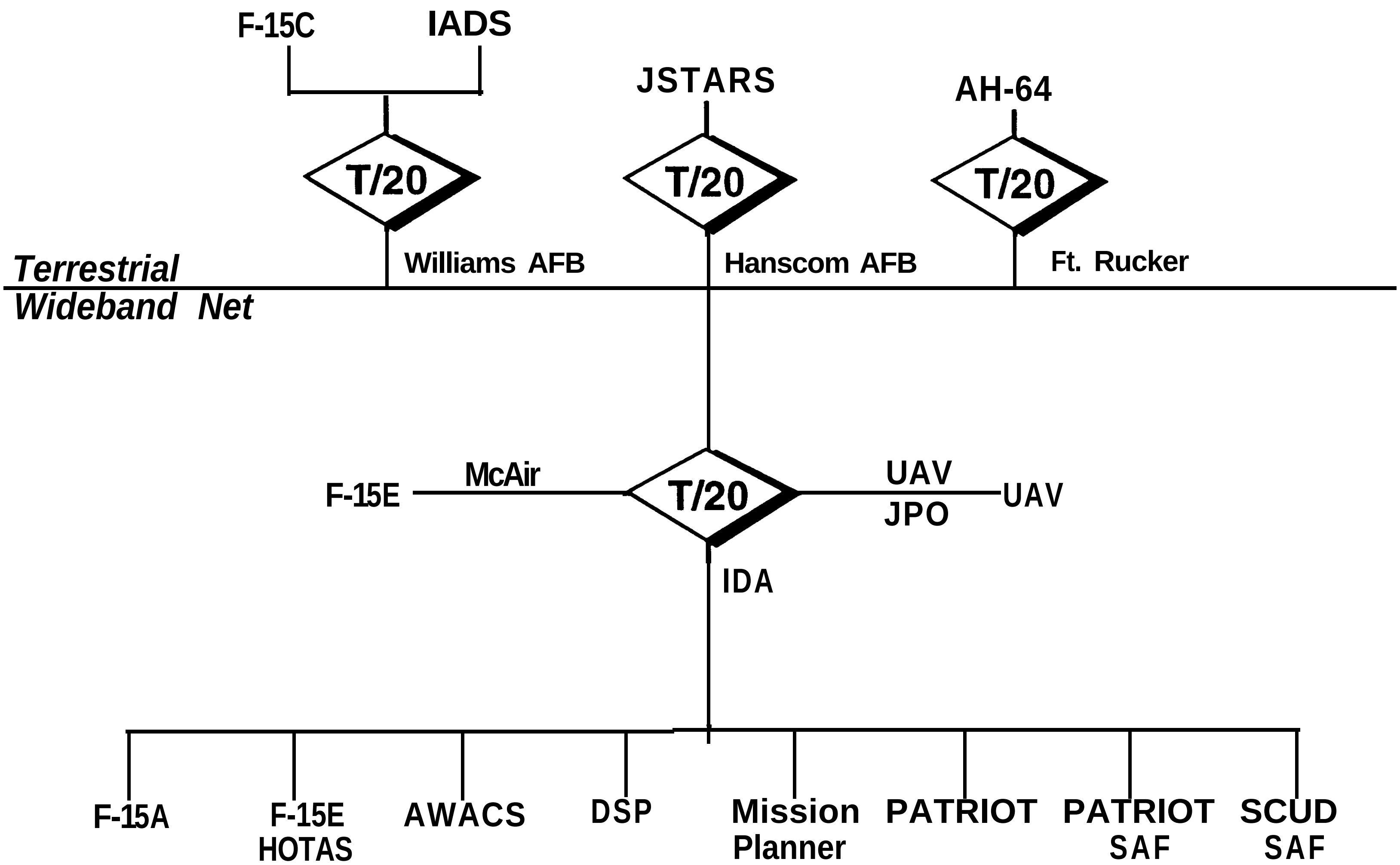
Greater standardization in the construction of simulators, both in terms of their component structure and services, would allow for a more ready translation between two simulators (see next subsection for a discussion of services). In a more speculative vein, significant further research in “intelligent intermediaries” would be required to develop a translator that would have sufficient internal capability to allow it to develop the translation between the given simulator and the standard protocol automatically. An advanced problem of that nature is probably best approached by working first to achieve the automatic translation in terms of a fairly narrow domain for the types of simulators considered.

Simulation Operating Systems

The discussion thus far has focused on structure and interfaces, but the general services provided by a system are also considered a part of its architecture. Certain basic services are common across many, if not all distributed simulations. These include geometric services (e.g., detecting when a collision between two objects occurs) and physical services (e.g., the

5 For example, the cost of integrating the F-15E domed simulator into War Breaker was approximately $400,000.

Figure 8
INTERNETTING DISSIMILAR SIMULATIONS (WAR BREAKER, PHASE I)



effect of gravity on a physical object of a certain mass). Normally in computing systems, basic services (e.g., file services) are provided in a common system (e.g., the operating system) that is available to all users so that they do not have to reinvent these services. Then the users can focus on the unique aspects more immediate to their task at hand. Furthermore, consistency among the different users is promoted by having a common set of services. However, in distributed simulation a set of these services-a so-called simulation operating system-does not generally exist now (although there are limited attempts at providing such capabilities).

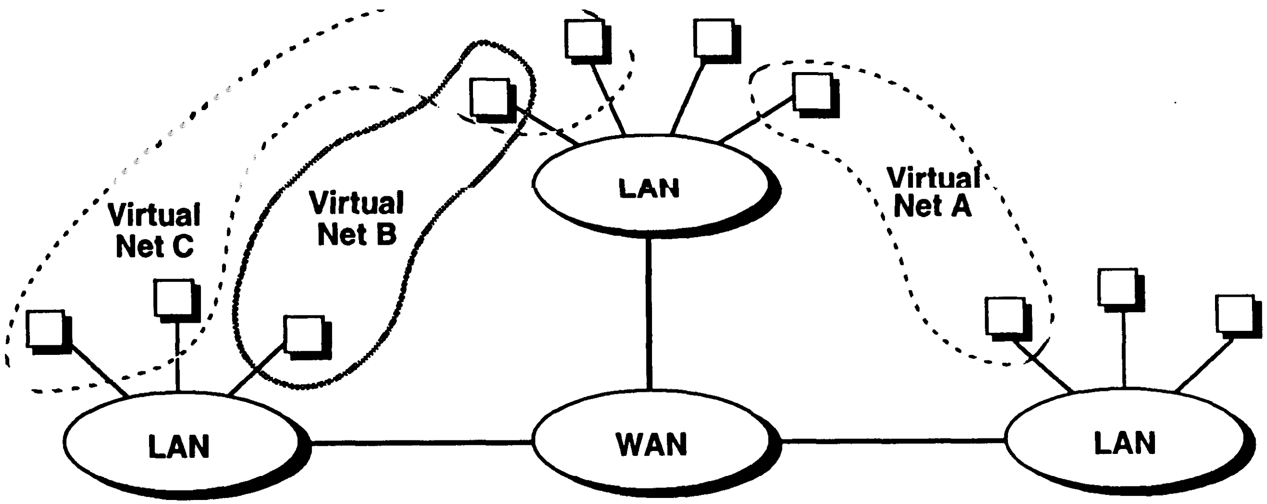
Thus, effort should be given to providing such a simulation operating system. It need not start from scratch, but can draw on a body of existing work. Examples include the time management provided in conventional operating systems and the "reasoning" about objects carried out in current graphical and computer-aided design (CAD) systems. Furthermore, the distribution of the services can draw on the technologies (e.g., distributed operating systems) developed for distributed computing in general. Still, basic work remains in developing the virtual environment abstractions, interfaces, and protocols that would be used for the simulation operating system.

Communication Architecture

A means for communication between simulators underlies distributed simulation. Currently, the communication architecture is such that all state information (i.e., the protocol data units) is sent to all simulators on the network, even if that information is of no relevance to a given simulator. For example, exchange of state information by two tanks separated by 100 miles is of no relevance because the two tanks cannot directly interact with one another. To limit the network communication load and processing by individual simulators, only that information required by a given simulator should be sent to it. This need becomes particularly acute as the number of objects in the simulation grows.

One way for meeting this need is through the concept of virtual nets (see Figure 9). Two ingredients are necessary for such nets: (1) the means to set up the subnets and (2) the capability to decide which simulators should subscribe to each net. Multicasting technology should provide the means to set up the subnets. Multicasting capabilities are being developed and are projected to be available in commercial networks in two years or less. However, the ability to adjust the subnets dynamically, as required to support the real-time demands of manned distributed simulation and the changing battlefield, is beyond the needs currently anticipated in the commercial sector. The capability to

Figure 9
VIRTUAL NETS



Networks:

- Avoid unnecessary traffic on communication links
- Take advantage of localilty (e.g., geographic grid, line-of-sight, military hierarchy,...)
- Must operate in real-time

System Applications:

- No single entity has global state
- Recording a simulation should not defeat the network (multiple recorders)
- Creating and controlling the virtual networks in real-time is an issue

decide which simulators should be on each subnet depends on some form of model-based reasoning. Two issues are relevant here: (1) the criteria used for the model-based reasoning, and (2) where in the simulation system this reasoning capability should be located. The most obvious criteria would be based on location in virtual geographic space, but other possible approaches (e.g., based on organizational relationship of the military units) should not be ruled out at this early stage. Location of this reasoning capability could either be in the host simulators or in the network itself. Just which choice is made would have to be determined, based on detailed system architectural and tradeoff analyses.

Virtual nets are an obvious way for approaching distributed simulations with increasing numbers of objects. However, other relevant concepts for dealing with this problem may exist-one such is the notion of aggregation. Rather than always dealing with objects at the lowest level of description (e.g., tanks), it might be useful to deal instead with aggregated objects (e.g., platoon or battalion). The notion of aggregation is a powerful one in science-for example, the bulk properties of matter are more readily predicted by using thermodynamics than atomic physics. So there is the general belief that aggregated abstractions should also be useful in dealing with simulations with very large numbers of objects. However, in the types of simulation envisioned here, the deaggregated description must be recoverable since there is always the possibility that some observer will need to see the individual object on the simulated battlefield. Treatment of such deaggregation will most likely require fundamental research.

Proposed Experiments and Research

Both near-term experiments and longer-term research activities should be undertaken to resolve the issues noted above. The experiments will provide for a better understanding of the problems and the research will furnish the theoretical basis for long-term, enduring solutions. A first cut at such experiments and research is given in Figure 10, “Architecture/Networking: Proposed Near- and Long-Term Activities.” The issues have been rolled up into two broad categories, as indicated by the two goals in the figure. The near-term realization of the goals is primarily in terms of experiments that will provide the basis for research leading to the long-term realization of the goals. An application framework would provide the generic services discussed above under simulation operating systems. The first steps recommended toward achieving the framework are to (1) lay out a standardized notion of the major simulator components (since those components use the generic services), and (2) conduct some experiments using basic geometric and physical services in a rudimentary distributed configuration. Then, in the longer term, a fully distributed system offering a broad set of

Figure 10
ARCHITECTURE/NETWORKING: PROPOSED NEAR- AND LONG-TERM ACTIVITIES

Goal	Near-Term Realization	Long-Term Realization
Application framework providing generic simulation services on a universal basis.	Standardize internal simulator architecture Provide basic geometric and physical services in rudimentary distributed configuration	Provide complex services (e.g., Terrain Server) with full distribution
Communication network optimizing use of resources	Demonstrate IP multicast for simulation Experiment with geographic rules governing distribution	Establish multicast network with model based distribution Explore models for object aggregation and deaggregation

services, such as description of the environment to the participating simulators, would be addressed. Because of the complexity of the calculations involved in maintaining a description of a changing environment with dynamic environmental phenomena, it may be necessary to calculate and hold such environmental information at selected sites and then furnish portions of this information to given simulators as required.

With regard to the communication networks, a wide base for employing multicast technology should be built up. For example, experiments involving the Internet Protocol (IP) are suggested. Likewise, experiments with setting up virtual nets based on rules referring to location in virtual geographic space are recommended to pave the way for longer-term research in model-based distribution. The last topic noted in Figure 10-models for object aggregation and deaggregation-is a fundamental but potentially very difficult area in which to make progress. Thus, only further exploration of this area rather than a well-defined implementation is proposed at this time.

VII. SYNTHETIC ENVIRONMENTS[6]

Synthetic environments provide the dynamic electronic battlefield with terrain data (earth surface and man-made structures), bathymetric data (for some applications), and meteorological and near-earth space information. This information is required to support visualization, vehicle movement, sensing, weapon firings, collisions, inter-visibility, and other battlefield effects. The quality and resolution of data needed will vary with the mission. Generic training missions can tolerate much lower fidelity than mission rehearsal. The two most critical needs for distributed simulation synthetic environments are (1) support for the rapid generation of high resolution, attributed data with cultural artifacts, and (2) support for dynamic changes to the environment, including actual changes in terrain features as well as weather. The current state of the practice with respect to meeting these two needs will be

6 This chapter is based on material from the 1992 DARPA Information Science and Technology (ISAT) summer study on simulation technology. The chapter was written by Randy Garrett, a member of the ISAT summer study team.

considered in next section, followed by proposed solution concepts.

State of the Practice

Spatial data is the backbone that supports the creation of synthetic environments. Currently, the needed data must be gathered from a variety of sources with inconsistent representations and resolutions and manually pieced together in a painstaking process. Semi-automated terrain compilation and cultural feature collection require extensive manual intervention. Total time to construct a new spatial database ranges from many weeks to six months or more.

Current spatial databases contain limited detail. Only aggregate feature descriptions are available, and those are mostly coarse grain. Feature attribution is a fully manual operation. Just thirteen surface material codes are in common use. Aggregate (average) heights are normally used. Elevation resolution is generally only sampled every 30 to 100 meters. This level of resolution is inadequate for capturing anything other than the largest cultural artifacts. Mountainous terrain or other irregular terrain may also not be captured adequately for some missions.

Very limited database sharing is possible across multiple simulators. Separate representations are required in order to support computer image generation, two-dimensional map displays, and analytical needs. There is very little reuse of environmental data or the software to create and use it. Each set of data is compiled for specific needs and is often inappropriate for other missions.

Temporal changes to the environment should be supported to provide realistic battlefield effects. At this time, only static database representations are available except for some limited laboratory experiments. Instead, if the terrain is altered due to weather or effects of war, the changes are represented through the use of special icons, or other graphics "tricks." The terrain itself is not really altered.

Little physical modeling of environmental effects or sensors is currently performed. Only very simple interactions between simulation objects and the environment are modeled. Radar, infrared, and night vision have been employed in a few scenarios using coarse approximations of the true interactions.

Rapid Construction of Synthetic Environments

The first critical need is support for the rapid construction of detailed large-scale spatial databases. A major problem is the lack of appropriate baseline data. The problem starts with source data collection. Many diverse sources of information must be used, precluding the ability to acquire all the needed data from one agency. Dealing with multiple sources not only creates an increased paperwork and logistics barrier, but also almost guarantees numerous inconsistencies and incompatibilities.

An issue is the difficulty involved in fully automating the construction process, resulting in substantial manual intervention. One example of this problem is the complexity involved in creating comprehensive feature attributes. Many types of feature attributes must be included. Each feature may need specialized information associated with it that is complex and difficult to obtain. For instance, to attribute fully a forest type, we need to know data such as its basic composition (e.g., deciduous, tropical), the percentage of foliage cover, and the age or maturity of the forest in order to determine the average tree height. As a consequence, large quantities of information must be obtained and mechanisms provided for the storage and rapid retrieval of this information from the terrain database. Determining the correct information to store is difficult and normally requires consulting multiple sources. Feature attribution data, particularly at a detailed level, cannot be obtained directly from an aerial photograph. Similar issues apply to obtaining and storing cultural artifacts. Physical modeling of environmental and sensor interaction will require appropriate supporting data as well.

Considerable need exists for the sharing of synthetic environments to support interoperability of diverse simulations, including a continuum of realistic visual representations of battlefield environments. Currently, there is very little reuse of data and software. One problem is the lack of standards to support data sharing. Unfortunately, some of the proposed standards impose a serious penalty on usability and the amount of database storage required. For instance, one proposed standard, Project 2851, stores terrain data in a flat ASCII file, resulting in file size increases of an order of magnitude or more with concomitant increases in loading time. Given that even efficiently stored terrain databases are tens to hundreds of megabytes in size, any acceptable standard must also store data efficiently.

Finally, there is a legacy of installed simulator bases which represents a considerable investment. These systems use proprietary detailed object models that incorporate level of detail techniques and representations tied to graphics “tricks.” This approach improves the cost-to-performance ratio at the expense of portability and standardization.

Several development opportunities exist to speed the construction of synthetic environments. An important foundational task is the creation and integration of technology to support large-scale, heterogeneous, spatial databases. Work is ongoing to create large-scale databases, heterogeneous databases, and spatial databases, but very little has been done for databases which can support all three attributes simultaneously. The community also needs integrated tools to leverage the largely manual cartographic compilation systems in use today. These tools should support database intensification, automatic baseline production with smart editing, and the acquisition and analysis of multispectral and hyperspectral imagery data. The development of techniques for terrain compilation from a common database to support diverse simulators with varying fidelity constraints could also help speed construction by reducing the total effort required to construct all the requisite databases and also by helping to maintain a consistent representation.

Dynamic Environments

The second critical need is for dynamic modeling of terrain and cultural changes, including environmental, sensor, and battlefield weapons effects. An initial problem to be overcome is the current static terrain and cultural models. There is no support for such things as bomb craters, revetments, and damage to structures. These changes are currently modeled as "icons" which just give a visual illusion of change, but since the terrain is not actually modified, other objects in the simulation are unaware of the changes. For example, a tank will roll smoothly over a crater with no dipping or tilting. Laboratory work has begun to investigate these problems as proof of concepts, but much work remains to be done.

A concommitant problem is the lack of physical modeling in the simulation. Once a change to the dynamic environment is available, it must be used to affect realistically the other objects in the simulation. Little use is currently being made even of the static feature attributions available. Sophisticated simulation models may be involved if smoke dissipation, stream flow, point light sources, and other complex physical physical phenomena must be accurately represented. Appropriate ways of visualizing the effects of these physical models must also be addressed. Dynamic environments in conjunction with physical modeling will require considerable additional computational power to compute and display the real-time results of the models, stressing the computer graphics generators and, possibly, the network as well. Appropriate synchronization of changes must be supported by the distributed simulation architecture to ensure that all players are operating with the same terrain. Supporting sensor modeling, particularly for electronic warfare, will compound the physical modeling issues by imposing tight time constraints and the need to order interactions. Sensor models might also flood the network with packets.

The technology development areas suggested for the rapid generation of synthetic environments are, naturally, also important for supporting dynamic environments. The increased complexity of dynamic environments, however, requires additional effort in several areas. First, architectural questions of where to place the computational burden and how to communicate changes efficiently must be addressed. The computational burden might be addressed through the incorporation of high capacity servers onto the simulation network. This change would have architectural as well as network implications. Network protocols may need to be revisited as well. Another means of addressing the computational requirements might be to apply Application Specific Integration Circuits (ASIC) or other microelectronic technology to the dynamic environment problems by producing custom chips specialized for these demands. A need also exists for algorithmic research to support real-time update rates for physical models. Numerous physical models of all types exist, but almost all of these were created for a very different set of constraints.

Accurate display of the synthetic environment, particularly dynamic modifications, must also be considered. Standards for computer image generator programming interfaces need to be set to address the unique demands posed by distributed simulation. These unique demands include the need to maintain real-time update rates, the necessity of providing a "fair fight" via the maintenance of common fidelity across simulators, and the uneven graphics loading due to clustering of activity. Densely populated dynamic battlefield environments can easily exceed real-time image generation capability. In addition, there is the difficulty of providing photo-realistic rendering under real-time constraints. The range of image generator requirements varies greatly from SIMNET at one end with relatively low fidelity by current standards to SOFATS at the other with very high fidelity to support specific mission rehearsal requirements. A standard interface is needed to support a continuum of realistic visual representations for the battlefield environment.

Conclusions

Accurate representation of battlefield environments is a very challenging area. The first difficulty to be overcome is rapidly constructing a high resolution database with appropriate terrain attributes and cultural artifacts. This problem can be addressed by (1) improving the base technology for creating large-scale, heterogeneous, spatial databases; (2) developing automated aids for the population of the spatial database; (3) increasing the availability of national asset intelligence imagery; (4) supporting the production of multiple databases from a common source; (5) promoting the interoperability of database products once created; and (6) identifying the best network protocols to support synthetic environments.

Battlefield environments are inherently dynamic, yet current systems only support static terrain. This limitation could be ameliorated by (1) algorithmic research to support real-time update rates for physical models, (2) architectural support for terrain servers, and (3) production of high-speed custom chips. The technology development areas identified for the rapid generation of static synthetic environments would, of course, also be needed for dynamic terrain.

Finally, accurate display of the synthetic environment, particularly dynamically occurring changes, must also be considered. The most crucial need here is the creation of a standard graphics interface that can support the unique demands of real-time distributed simulations, yet be portable across diverse hardware platforms.

VIII. APPLICATION OF ADVANCED SOFTWARE TECHNOLOGY TO DEVELOPMENT OF COMPUTER GENERATED FORCES[7]

Automated Forces

Automated forces are used in distributed simulation environments both to augment the number of human participants and to replace human participants. Augmentation is the most common application, where a small number of humans is to evaluate a new weapon, or be trained, in a situation that requires either a large number of forces, or forces that are not directly available (such as particular opponent forces). Replacement occurs in situations where humans cannot directly participate; for example, in what-if simulation, where the faster than real-time requirements make direct human participation impossible.

7 This chapter is based on material from the 1992 DARPA Information Science and Technology (ISAT) summer study on simulation technology. The chapter was written by Paul Rosenbloom, a member of the ISAT summer study team.

This section assesses the use of automated forces in distributed simulation environments. We first assess the current state of the art, as reflected in SIMNET, and present the vision of what is really needed. Both of these aspects will be characterized along four dimensions: timeliness, granularity, heterogeneity, and cardinality.

- Timeliness deals with both the ability to create automated agents within the requisite time frames, and the ability execute them at the needed rates.
- Granularity deals with the level of the force (such as company or battalion) and the amount of detail at that level.
- Heterogeneity deals with the variety of force types that can be provided.
- Cardinality deals with the number of forces that can be provided at the given level of granularity.

We then discuss three key barriers in reaching this vision: integration of improved functional capabilities, timely construction of automated forces, and real-time intelligent performance. For each barrier we provide an assessment of current technology with respect to it, and discuss the technology thrusts most needed to overcome it.

Current States of the Art in SAFOR

The current state of the art is represented by the SIMNET SAFOR, and its immediate successors. On timeliness, it currently takes days to months to create a new force depending on how much the new force differs from existing ones. Once created, the forces run at about 50 times faster than real time; that is, 50 vehicles can run on the same workstation, and still achieve real-time performance levels. Because these forces are all of quite limited intelligence, the issue of being able to achieve specific deadlines has not needed to be a major research thrust.

On granularity, the forces are limited to individual vehicles with simple intelligence (up to companies of them). There are no models of commanders at higher levels, and the current level of coordination, even at the company level, is limited to simple group behavior (such as maintaining formation). Groups can exist up to the battalion level, but require intensive user intervention. The individual vehicles are also quite limited in terms of their own capabilities. They can follow scripts with simple conditionals and limited interrupts but can exhibit very little flexibility in unexpected (free play) situations, or reactivity to the current situation (as opposed to just following its script). There is no learning (either short-term adaptation to the environment and the other agents or long-term improvement in ability). Simple navigation and obstacle avoidance are provided.

On heterogeneity, a range of types of forces have been developed, including tanks, helicopters, fixed-wing aircraft, and dismounted infantry. There is, however, not a great deal of experience in mixing large amounts of these various types together.

On cardinality, SIMNET is currently limited to about 1,000 vehicles. We know of no limitations that would restrict the number of automated forces to less than this number.

Vision of Automated Forces

What is ultimately needed here is the ability to quickly create large numbers of real-time agents of different kinds at all echelons. On timeliness, the need is for force creation or modification in hours to days. This is particularly critical for operations planning, but still quite desirable for training and acquisition, as it determines the cycle time for iterating through changes. Once created, the forces must run in real time, both in terms of raw speed and in terms of their ability to meet deadlines that arise (such as reacting to be being shot at, or being in a particular defensive position by a particular time). Faster than real-time performance is also quite desirable in other applications, such as what-if simulations, where the need is to run multiple alternative scenarios in a short period of time.

On granularity, the need is for autonomous intelligent individuals at all echelons. As the echelon gets higher, the requisite capabilities become increasingly cognitive and decreasingly perceptual motor. A key here is that tactics, plus an interpreter for the tactics, does not equal intelligent forces. In particular, there are at least four core capabilities required of intelligent forces that take them beyond just the following of tactical scripts.

- The first core capability is reactivity and short-term adaptation, to enable the force to deal effectively with time-limited emergencies (such as being shot at) and to alter its behavior sufficiently so as to not cause such situations to repeatedly occur (such as when a dismounted infantryman repeatedly comes out from behind a barrier because it does not remember that it is being shot at, or cannot effectively adapt its behavior to the changed situation).
- The second core capability is the ability to fall back on more fundamental knowledge and reasoning (such as planning in dynamic three-dimensional worlds). When the situation does not exactly match what the force knows or-even worse, when the situation is quite novel-the force must be able to adapt its existing tactics, or construct new ones, in order to respond appropriately.
- The third core capability is cooperative problem solving and reasoning about adversaries. The

forces must be able to work with other friendly forces, and to reason about opposing forces (for example, to enable counterplanning).

- The fourth core capability is to exhibit the other capabilities in a human-like fashion. There may be times when superhuman (or, more generally, nonhuman) performance is desired, for example, in overtraining where a trainee is pushed beyond what he or she is actually expected to see. However, under most situations, realistic behavior is required and this demands that the automated forces behave as would humans in comparable situations.

Beyond these core capabilities, there are extended capabilities that do not seem quite as essential, but that are still important, particularly in specific applications. Learning is needed to reduce the effort required to construct automated forces by (semi-)automatically acquiring tactics from traces of human behavior, to improve reactivity by compiling planning down into reactive behavior (much as people can automatize behavior that earlier required significant cognitive effort), to improve quality of behavior (i.e., realism) by learning about the environment and the behavior of the other agents, and to challenge experts over multiple engagements by altering behavior as a function of what the expert does. These extended capabilities not only help out in specific applications, but they can also provide strong synergy with the core capabilities, such as when the addition of learning to a planner greatly increases the capabilities of the planner. Extended capabilities can be quite difficult to add as afterthoughts, so they need to be anticipated in initial designs.

On heterogeneity, the need is to automate all of the types of forces involved in the engagement, including support forces. For example, if a simulation is to be used to evaluate a logistics plan, the details of how that plan will be carried out, and how this interacts with the rest of the engagement, must be realized.

On cardinality, force sizes of 10,000 to 100,000 are needed for the kinds of large scale simulations envisioned.

This combination of requirements is clearly quite demanding, but can be done in the long term. More positively, not all of this is needed before useful automated forces can be fielded. The SIMNET SAFOR, even with all of its limitations, has shown itself to have definite utility. A conservative development beyond this, using only commercial expert systems technology, could also get significantly beyond this level. Beyond this, almost any amount of additional progress that can be made in removing three fundamental barriers will yield more functional automated forces. The three barriers are discussed in detail in the following sections.

Barriers, Assessments and Thrusts

Barrier 1: Integration of Improved Functional Capabilities

The barrier here is the very mixed state of development of the various core and extended capabilities and the little that is known about how to perform the coordination and communication required among them.

As mentioned previously, a fair amount of progress can be had by just shifting to conventional expert systems technology. This would not solve many of the problems, but would definitely improve realism and flexibility. However, rather than focusing on assessing this technology here, we focus instead on an assessment of the state of the art in artificial intelligence research with respect to each of the individual capabilities (and their integration). It is these capabilities that will need to be improved and integrated to get close to the vision of automated forces.

The capabilities themselves can be categorized as either being in good shape, being in good shape under relatively strong limiting assumptions, or being nascent (i.e., some are known, but little has been done). Reactivity, and the conversion of planning to reactivity, are both in relatively good shape. General planning is well understood for small static worlds, as is path planning in static worlds with limited quality criteria. Reasoning in more detail about space and time is possible under limited circumstances (as investigated in work on scheduling, reasoning about temporal intervals, temporal data base management, and geometric reasoning). Natural language and explanation are both possible in simple well-understood domains. Cooperative problem solving is possible for a small number of agents in simple domains; however, opponent modeling is nascent. Also nascent is learning by observing experts, learning about the environment, and learning about opponents. Providing all of these capabilities in a human-like fashion is also very nascent, though at least two integrated architectures have now taken on this task head on, and made some significant progress.

On integration, over 30 architectures have now been developed that combine at least 2 of the needed capabilities (including the 2 architectures that are explicitly trying to model human cognition). Some of the more advanced such architectures incorporate, for example, some form of reactivity, planning, use of knowledge, natural language, and learning. However, there is still a long way to go before an architecture will exist that effectively integrates together reasonably robust and general versions of all of these capabilities.

If the barrier is compared with the assessment, and then these differences are prioritized, the result is a list of important technology thrusts for this barrier. The most important thrust is the development of architectures for the integration and modeling of human cognition (partially there but very hard). Among the individual capabilities, improvements are most needed on planning in dynamic three-dimensional worlds (partially there but moderately hard), learning in the context of simulation agents (partially there but moderately hard), and opponent modeling (nascent but should not be too hard).

Barrier 2: Timelv Construction of Automated Forces

The barrier here is that it currently takes months to construct automated forces, and it will be much worse as they become more sophisticated. Back-of-the-envelope calculations show that core agents will require between 1,000 and 10,000 rules, while extended agents may require up to 100,000 rules. The largest hand-coded (i.e., not learned) systems are currently about 10,000 rules (or, in a different technology, about 50,000 frames).

At the standard knowledge acquisition rate of 1 to 3 rules per hour, it will take 2 to 6 months to acquire the simpler 1,000-rule core agents. The 10,000-rule agents would require 2 to 5 years, while l00,000-rule agents would require 20 to 50 years. Compared to the hours-to-days desired for the construction of new forces, there is clearly a large mismatch.

The knowledge-acquisition rate of 1 to 3 rules per hour is based on two assumptions: (1) good representation languages and tools exist for the domain of interest, and (2) it is necessary to get the knowledge directly from experts. If assumption 1 is relaxed, acquisition can take much longer. If assumption 2 is relaxed-for example, if much of the knowledge is codified in books and manuals-acquisition can be much quicker. One approach that may help significantly in further improving these rates is the creation of one or more generic force agents. Such an agent would have many (or all) of the capabilities discussed in the previous section, but would not necessarily have them specialized to the needs of a particular individual (such as a tank or division commander). Given such generic agents, it may be possible to copy-and-edit or specialize them to be new particular individuals in much less time than it would take to create one from scratch. One interesting but quite limited version of this type of capability is the Modular SAFOR now being developed for the WISSARD/IFOR program by DARPA. This will provide an interface so that intelligent forces can directly utilize the low-level capabilities provided by the existing SAFOR, rather than having to reconstruct them from scratch.

One critical technology thrust for this barrier is the development of one or more generic agents that can be edited and/or specialized into new agents (nascent and very hard). The Modular SAFOR is a limited step in this direction, but the basic must be extended to much more functional agents. The other critical technology thrust is the development of languages and tools for the acquisition of dynamic real-time tactical behavior (partially there and moderately hard). Existing languages and tools are almost universally focused on static timeless environments.

Barrier 3: Real-Time Intelligent Performance

The barrier here is achieving the requisite level of boundedness (i.e., ability to meet deadlines) and speed at all levels of the software and hardware.

On the boundedness side, there are no current intelligent systems that run in guaranteed real time at all levels of the software and hardware. There is, however, substantial relevant work in the areas of anytime algorithms (which always have an answer available, and just improve this answer over time), time-sensitive reasoning (which determines what methods to use as a function of the time remaining), new operating system kernels, and real-time expert system shells (such as real-time production systems).

On the speed side, we need to estimate how much computation will be required to run, say, 10,000 automated forces. From psychology we can estimate that humans take a minimum of 100 msec (millseconds or 10^{-3} seconds) to make a decision. If we assume that an automated force could therefore run in real time if it can also make decisions in 100 msec, and estimate that a 10,000 rule system can currently decide in a minimal 100 msec on an approximately 10 mips workstation, then it will require about 100,000 mips to field 10,000 automated forces in real time. It may require more computation for larger systems, but we know at least that, with good match technology, the slope of change is very small at around 10,000 rules. Also, to the extent that faster than real-time is required, the needs increase correspondingly. However, we also know that a combination of code optimizations and faster workstations should reduce the net cost by an additional factor of about 10 within 5 years.

Other approaches to improving speed, and allowing cheaper simulations with large numbers of forces, would be to look at aggregating (and abstracting) individual forces into higher-level forces. At the simpler end, this could involve a uniform predefined level of aggregation. At the (much) more complex end, this could involve automatic aggregation and deaggregation of forces, and the integration of forces at multiple levels of aggregation. Some is known about aggregation and abstraction, but many hard technical issues remain (especially at the more complex end).

One critical technology thrust for this barrier is the development of real-time hardware and software at all levels; that is, each level must be fast enough and sufficiently responsive to deadlines to allow the overall forces to perform effectively within the time available (partially there and moderate-to-very-hard). The other critical technology thrust is force aggregation, deaggregation, and integration techniques (nascent and very hard).

Summary

Additional effort is most needed in three areas:

- Integration of improved functional capabilities. The critical technology thrusts are in architectures for integration and modeling of human cognition, planning in dynamic three-dimensional worlds, and learning and reasoning about other agents.
- Timely construction of automated forces. The critical technology thrusts are in generic agents, and languages and tools for acquiring dynamic real-time tactical behavior.
- Real-time intelligent performance. The critical technology thrusts are in real-time hardware and software at all levels, and techniques for aggregating, deaggregating and integrating sets of agents.

IX. APPLICATIONS OF M&S TECHNOLOGY TO ENGINEERING DESIGN AND MANUFACTURING[8]

The Integrated Product/Process (IPP)

The DSB Task Force examining Engineering in the Manufacturing Process has defined a new term or concept. The new term is Integrated Product/Process (IPP) or IPPD, with the "D" meaning development. The IPP is a management process employing multifunctional/discipline teams for the execution of the process. In effect, the IPP is a total set of principles and practices that integrate all activities from product concept through production and field support. The approach in IPP involves optimizing system design ***and*** manufacturing process capability.

The purposes in coining the IPP concept are twofold:

(1) To balance product performance and process capability by using target unit cost as a figure of merit for decision making, and

8 This section was adapted by permission from the DSB Task Force on Engineering in the Manufacturing Process.

(2) To achieve a specified level of product/process maturity during each phase of the acquisition process.

Modeling and Simulation in IPPD

Modeling may be defined as

producing a representation or simulation of,

whereas a model is defined as

a system of postulates, data, and inferences presented as a mathematical description of an entity or state of &airs.

Simulation may be defined as

the imitative representation of the function of one system or process by means of the functioning of another.

These definitions, which are most closely associated with concepts of modeling and simulation in concurrent engineering, suggest that there are distinctly different technical approaches to the essentially synonymous functions of modeling and simulation. The scope of M&S approaches, suitable for IPPD, includes the following:

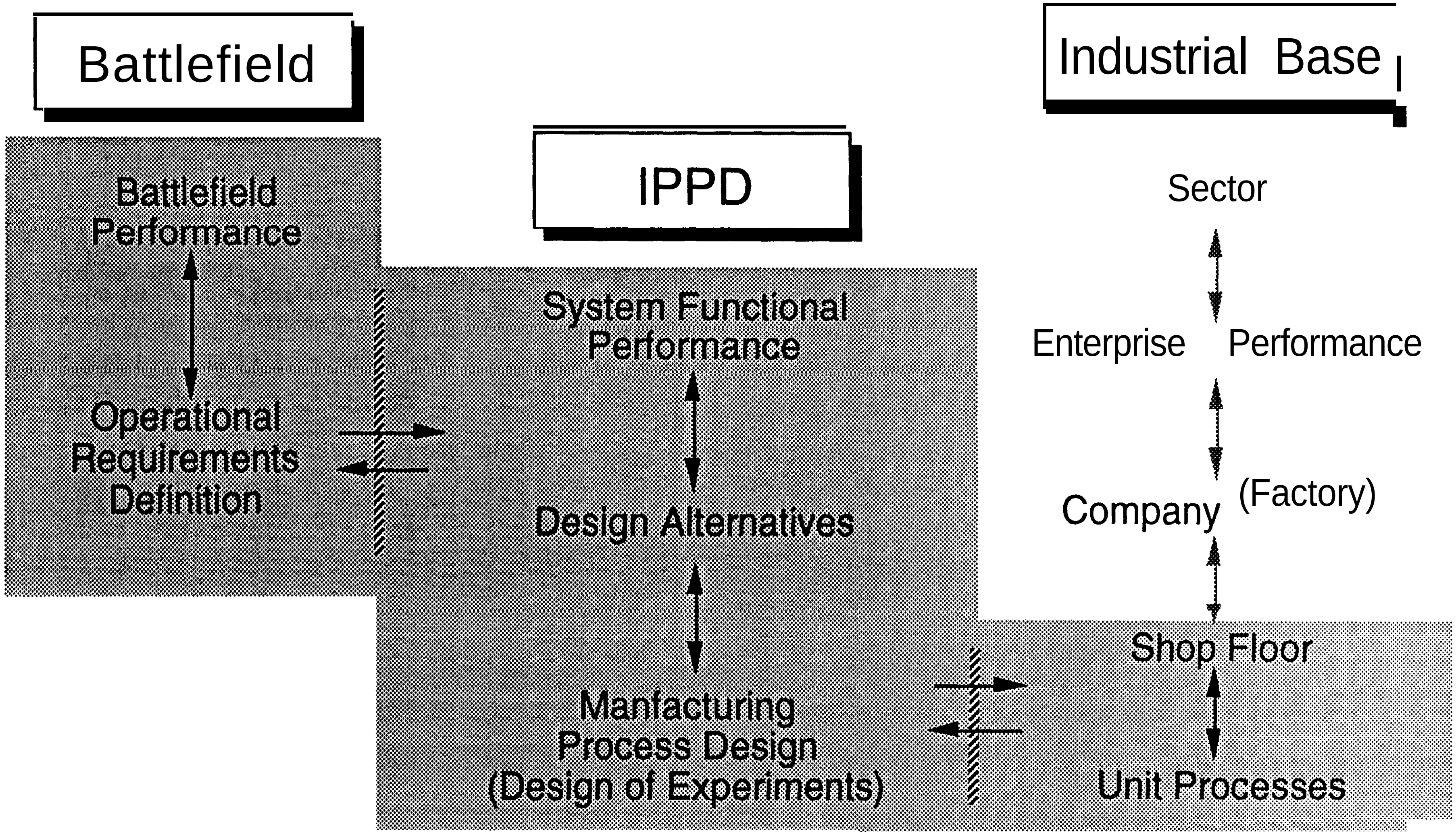
- Mathematical models
- Warfighter- and hardware-in-the-loop simulations
- Physical experiments

Illustrated in Figure 11, "Interrelationship of Battlefield to Industrial Base," is the future vision of how the battlefield is tied to the industrial base and ultimately to the factory floor through the product and process design environment. The vertical arrows on the right indicate the types of iteration activities that can be envisioned between model elements within a "functional" simulation environment. This is a "feed up/feed down" information exchange. The solid arrows indicate areas where evidence suggests that increased M&S capabilities would add value in the DOD product and manufacturing process development process. The arrows in the Industrial Base "functional" environment are dotted, because it is less clear at this time how much value modeling and simulation could add to the process.

If all the appropriate modules in each "functional" area were developed, and if a standard architecture, data transfer format, and network/module protocol existed, then the horizontal arrows would indicate the appropriate level of information exchange between the respective "functional" simulation environments. This is the communication link that allows for "feed-back/feedforward" capabilities for decision making across various "functional" environments.

Complementing well-established physical experimentation and empirical model approaches to simulation, some technological developments are underway to bridge the

Figure 11
INTERRELATIONSHIP OF BATTLEFIELD TO INDUSTRIAL BASE



SIMULATION, READINESS & PROTOTYPING

gap between battlefield simulation, simulation in support of IPPD, and industrial base simulation.

Distributed Interactive Battlefield Simulation

A gap exists, however, between SIMNET warfighting simulation capability and engineering simulation capabilities to create rapidly and cost effectively feasible weapon system and manufacturing process designs. The use of warfighters in the loop eliminates assumptions that are inherent in the modeling of human behavior, and thereby increases confidence in results of the simulation. System performance is an input to the simulation and SIMNET provides insight into how the soldier will actually employ the system on a virtual battlefield. Taken with SIMNET, emerging engineering simulation tools hold the potential to revolutionize the process of weapon system requirements definition, weapon system conceptual design, and evaluation of the impact of manufacturing capabilities on warfighting effectiveness in a realistic battlefield environment.

Warf'ighter-in-the-Loop Engineering Simulation

Recent advances in real-time weapon system simulation provide the potential for warfighter-in-the-loop real-time simulation of weapon system performance, at an engineering level of detail that is suitable for tailoring the design of the weapon system to the capability of the warfighter. Acceleration of initial developments will create a new engineering simulation capability that emulates proving ground prototype testing, using an engineering simulation in lieu of the physical prototype. This revolutionary new capability offers the potential to drastically reduce the time and cost of weapon system concept and prototype design. An extraordinarily powerful warfighter-in-the-loop engineering simulation tool is on the horizon, to bridge the gap between the newly created distributed interactive battlefield simulation capability and non-real- time computer-aided engineering (CAE) simulation capabilities that are reasonably well developed in the engineering community. The use of engineering modeling in the simulation of a weapon system eliminates the need for many of the performance assumptions normally associated with the modeling process. Properly implemented, warfighter-in-the-loop engineering simulation allows the designer to input the design parameters to the simulation and infer the performance. This permits tradeoff analyses between design alternatives, and is in contrast to the current method of simulation in which performance is an input. When combined with warfighter-in-the-loop battlefield simulations like SIMNET, comprehensive system performance assessments can be made.

Hardware-in-the-Loop Physical Simulation

Analogous to warfighter-in-the-loop engineering simulation, weapon subsystems that are difficult or impossible to model mathematically can now be incorporated in real-time simulation, in some cases with the warfighter in the loop, to determine performance characteristics of weapon systems and subsystems in a field environment. Hardware-in-the-loop physical simulators for weapon subsystems, tank-automotive subsystems, aircraft subsystems, and missile subsystems are emerging but still function in isolated subsystem development environments. They have not yet been integrated into a simulation environment to support both distributed interactive battlefield simulation and warfighter-in-the-loop engineering simulation. The use of hardware in the loop eliminates all assumptions related to subsystem performance and gives the truest indication of how the fielded subsystem will actually perform.

Weapon Performance Modeling and Simulation

Well-developed engineering analysis tools in numerous disciplines are available to relate design characteristics to weapon system performance in a non-real-time simulation environment. These CAE tools include structural finite element modeling and analysis, mechanical system dynamic modeling and analysis, armor penetration and vulnerability analysis, signature analysis, and a broad spectrum of discipline specific analysis tools that run on a range of workstations, mini-supercomputers, and supercomputers. For the most part, these CAE tools are well developed, but reside in isolated discipline-specific applications environments. They have not yet been integrated into an IPPD environment that can provide timely support to engineering decision making and data creation for the higher levels of M&S capability described in the previous sections.

Industrial Base Simulation

The manufacturing system involves the prime contractor and supplier chain. Production consists of piece part, subassembly, and full weapon system assembly. Any given major weapon system production base consists of hundreds of companies from several sectors, organized through the chain from producing piece parts to the final assembly of the system. The goal is to model the manufacturing system for the purpose of iterative examination of affordability traded off with performance by means of synthetic battlefield simulation. To accomplish this, all of the unit processes must be determined and modeled as part of a weapon system model. This model can then be designed to be robust against the requirements to meet durability, reliability, and affordability standards.

The approach taken to model the industrial base will be to focus on the critical unit processes and determine their characteristics by means of physical experiments. Unit processes have developed over time from factory experience. Computer systems employing data bases are used to determine their use in manufacturing. No attempt has been made to model the industrial base.

Architecture and Standards for Integration

As noted previously, numerous CAE M&S tools and a broad range of hardware- and war-fighter-in-the-loop engineering simulators exist or are on the horizon to support timely and cost-effective IPPD. However, they tend to be isolated, and communication among the numerous tools required to support weapon system and manufacturing process development is difficult. This results in unnecessarily slow and costly use of these tools in the design of weapon systems and associated manufacturing processes. To meet affordability objectives in the acquisition process, a uniform architecture and standards for seamless integration of this plethora of tools is required to create an IPPD environment. While some progress is being made, integration of M&S tools is in the very early stage of development.

Vision for Modeling and Simulation in the DOD Manufacturing Process

A vision for modeling and simulation in the DOD manufacturing process includes capabilities that can be achieved during the decade to support versatile and cost effective engineering and manufacturing processes. Elements of the proposed vision will be realized through an evolutionary process involving continuous test and validation of engineering M&S technologies in the Science and Technology (S&T) Advanced Technology Demonstration ATD process.

Modeling and simulation will progress to different stages for different sectors of the industrial base during the next three to five years. The degree to which each sector of the industrial base will be able to be modeled or simulated is unclear. Validation of models and simulations used in product and process design will be carried out in specific, sector-oriented ATDs. The ability to feed back and feed forward those capabilities will allow decision making to improve all aspects of the product life cycle.

Modeling and Simulation Utilized Throughout Product Development

Varying levels of M&S tools, some of which exist and others to be developed as an integral part of the S&T process, will substantially affect the DOD engineering process. Weapon system concepts will be developed, tested, and evaluated using simulation, with minimum essential prototype fabrication, test, and evaluation for the validation and benchmarking of capabilities and simulation tools. Distributed interactive battlefield simulation will be carried out using the existing SIMNET and its derivatives, involving the warfighter in assessing the value of new weapons and technologies in a combined-force battlefield environment. This revolutionary new distributed interactive simulation capability will be complemented by real-time hardware- and warfighter-in-the-loop engineering simulations and non-real-time engineering simulation tools to bridge the gap between the current engineering design environment and the new synthetic combined-arms battlefield environment. Engineering M&S capabilities developed and implemented during the decade will revolutionize the process of IPPD, including both design of the weapon system and its associated manufacturing processes. Improved fundamental understanding of manufacturing processes gained in process and modeling research will enhance the ability to optimize manufacturing processes for specific applications and will support tradeoff analysis of factory capability versus product cost, prior to entry into full-scale development of candidate weapon systems. Finally, the engineering M&S tools developed during the decade will permit maintainability, reliability, and related supportability specialists to participate in the weapon system design process at the very beginning, hence permitting supportability to be designed into the product.

Warfighter- and Hardware-in-the-Loop Engineering Simulation

Projects initiated by DARPA and the Army in warfighter-in-the-loop engineering simulations for support of acquisition will be intensified to emulate the costly and time-consuming conventional process of design, fabrication, and testing. Warfighter-in-the-loop engineering simulations will support engineering performance simulation at a design level of detail and account for human factors and fundamental human response quantification and measurement. This will create the level of realism required for design of weapon systems to function effectively in the hands of a broad cross-section of warfighters. Taken with carefully planned hardware-based experiments for simulation validation and parameter determination, a fundamental understanding of critical engineering tradeoffs will be achieved.

M&S Tool Validation

Significant developments in M&S tools will be carried out in joint ATDs. Through test and validation using real weapon system applications, confidence will be gained that product and manufacturing process simulations can be used in lieu of repetitive prototype design, fabrication, and test.

Environment for Information Feed-Back and Feed-Forward

DOD efforts that have been initiated to integrate advanced engineering tools for support of concurrent engineering of weapon systems will be accelerated, to create tools and technologies for affordability. Communication standards and format will be developed to permit effective electronic integration of the broad range of M&S tools that must function harmoniously to achieve the vision outlined above.

Issues

Six significant issues have been identified by the DSB Panel on Engineering in the Manufacturing Process regarding use of modeling and simulation in the engineering and manufacturing process.

- Can modeling and simulation be used to shorten the time and reduce substantially the cost of conventional prototype fabrication and test methodology? Judicious use of appropriate M&S methods, concentrating on critical performance and manufacturing process issues and taking advantage of available models of noncritical weapon performance and manufacturing capabilities, can significantly reduce the time and cost of the weapon system design cycle. Use of validated models in simulation of the weapon system and associated manufacturing processes can avoid one or more cycles of the conventional prototype fabrication and test process, hence significantly shortening the time and substantially reducing the cost of weapon system and manufacturing process design.

- What is currently capable of being modeled and simulated? Many aspects of weapon system performance are now capable of being simulated with confidence, whereas some performance-related design tradeoffs require real-time interactive warfighter- and hardware-in-the-loop methods that are under development. Only selected manufacturing processes can be mathematically modeled at present time using first principles. This requires that most simulations of manufacturing processes be carried out using physical experiments or empirical models based on experimental data.

- What should be modeled and simulated? Critical weapon system performance and manufacturing process characteristics should receive high priority for modeling and simulation in support of concurrent engineering. Care should be taken to avoid the evangelistic use of modeling and simulation when it is not needed. The least cost and time-consuming M&S approach should be adopted to meet specific high priority needs in product and process design.

- Does an infrastructure exist to support modeling and simulation? The major challenge in effective use of engineering modeling and simulation, particularly as regards achieving a rapid response simulation capability, is enhancing the poor infrastructure that is currently in place to support modeling and simulation. Individual discipline-oriented simulation tools exist, but most are embedded in specialized organizations. Data communications standards and tools to exploit the broad range of simulation tools required in weapon system and manufacturing process design do not exist.

- Can modeling and simulation guide selective investments in the industrial base? Models of the manufacturing industrial base are needed at a level of sophistication that reflects the impact of investments on product cost, production quantity, product quality, and industrial base responsiveness. Such a capability may or may not be feasible in the foreseeable future, depending on the industrial sector involved.

- Should modeling and simulation be used as a source selection tool? Many sectors of the industrial base are capable of using modeling and simulation as a discriminator for selection. This needs to be expanded (where feasible) to many sectors of the industrial base.

X. VERIFICATION, VALIDATION, AND ACCREDITATION[9]

Simulation As an Abstraction

By its very nature a simulation presents only an abstraction of the real world. We omit from our simulations any factors that are either irrelevant to the purpose of the simulation or too expensive to include. For example, we omit smells as both irrelevant and expensive, and we omit heat and dust as irrelevant. We simulate motion only when necessary because of its expense, and even the best simulations of motion suffer from severe physical limitations. It is physically impossible, for example, to simulate free fall on earth.

Omitting factors from a simulation is often a great aid to training. We can improve training rates by eliminating waiting periods. For example, training in the use of landing aids can

9 A recently completed working draft of a study on verification, validation, and accreditation, prepared for the Defense Modeling and Simulation Office (DMSO), provides a framework for systematically addressing the subject. See ***Generalizing Concepts and Methods of Verification, Validation, and Accreditation for Military Simulation,*** Paul K. Davis, Rand Report WD-6090-2-DR&E, August 1992.

begin with the simulator reset to the approach point to avoid wasting pilot and simulator time in the fly around. A gunnery simulation can have a ready supply of targets that would be unavailable in live fire. Moreover, by omitting irrelevant factors, we can concentrate on the central issues. Without the distraction of noise and heat, a trainee can better learn to use his controls and can better communicate with the training staff. Some kinds of team training, including social events, omit almost everything except the team to build human trust.

The risk, of course, is that we omit something important. How do heat and vibration affect crew performance? Does motion sickness degrade real performance in a way that the simulation fails to reveal? How great a factor is fatigue? Does the simulation require the proper level of visual acquity?

An Industrial Example

The design of a modem integrated circuit depends heavily on simulation on a more structured problem than a dynamic virtual electronic battlefield. Designers of integrated circuits are forced to use simulation because integrated circuits cannot be repaired and can ordinarily be tested only from their edges. Moreover, it can take many months to make a circuit from a new or even slightly changed design. Thus it is much better to detect design flaws by simulation before the circuit is built than to build dysfunctional circuits.

The circuit simulators used in the design of integrated circuits today are large and complex. They simulate the design on several levels. Logic simulators run test cases through the proposed design to see that the circuit blocks are connected properly. Timing simulators compute how long each part of the circuit will take to see that the actions mesh together properly. Analog circuit simulators are used where the electrical performance of the circuits is important, e.g., in sense amplifiers for memories and in clock drivers. Finally, geometric checkers test the layout against the complex fabrication rules of the target factory process.

It is common to do enough simulation so that integrated circuits containing a few million transistors will work properly when first built. In order to succeed, inordinate care must be taken in validating the simulation. Test circuits are used to calibrate the simulations. Different simulations are compared against each other to detect flaws. Smaller circuits are built with the same simulations to verify that the simulations produce valid results.

Even so, some new circuits fail to work as first built. Almost inevitably these failures can be traced to errors in simulation. In one case, for example, a “cache memory” chip worked fine, but too slowly. It turned out that the simulation ignored the electrical resistance of long wires, a factor that proved important only in larger designs and had not been of concern before. Because such failures cost time and money they are very painful. No wonder there is great effort to validate the simulations.

On the Importance of Validation

The validity of military simulation is even more important when lives and the outcome of conflicts are at stake, All military commanders have "models" of enemy behavior, some mental, some computer based, and some formalized in other ways. It is the job of intelligence to refine these models so that they more accurately reflect reality. Errors can be very expensive. For example, Hitler's model of communication security in World War II overlooked the great effort invested to break his codes; with a valid model he might have changed the course of the war.

But validation of military simulations is even harder than validation of integrated circuit simulations. What training will be required? What equipment will prove important? Would simulation have shown the builders of the Maginot line how it would be defeated? Even if people learn to do simulated tasks correctly, how transferrable is that training to the real situation?

Advanced Distributed Simulations

There are several different levels of detail at which simulation can be applied to battlefield performance. At one extreme is the "engineering" simulation, in which the physics of vehicle dynamics, weapons, and sensors are modeled in great detail. At another extreme is the large-scale mathematical wargame, in which details of engagement interactions are abstracted away, and the focus is on the statistical outcomes of large numbers of such interactions in order to explore the probable effects of some proposed strategy. In between these extremes lies a substantial "granularity gap" that can conceal many hidden assumptions about tactical behaviors and responses on both sides of an engagement. It is in bridging this gap, and in making potentially crucial assumptions more visible and susceptible to evaluation, that Advanced Distributed Simulation can make a substantial contribution.

One of the most vexing aspects of modeling battlefield engagements is that the introduction of any significant new elements-new weapons, new sensors, new tactics-will result in tactical adaptations and innovations on both sides of the engagement, which are very difficult, if not impossible, to predict. Generally, it will be necessary to conduct a series of "free play" exercises in which both sides are free to experiment with their behavior in order to determine probable outcomes.

Under these conditions, it becomes difficult to define what constitutes validation and verification of battlefield behavior. There are a fairly small number of parameters that consistently prove to be crucial across many simulations:

vehicle speeds and accelerations; target detection probabilities as a function of range, target type, terrain, weather, etc.; hit probabilities as a function of similar parameters; and so forth. These are, therefore, the most important elements on which to focus in validating model behavior.

To assess the validity of a battlefield simulation, it is essential that various subject matter experts trace the behaviors of representative entities and units to determine whether the logical flow of these behaviors is credible or "reasonable" under various circumstances. In order to be a valid simulation, it should not be required that vehicle crews and unit commanders, either live or semi-automated, respond exactly as the domain expert believes he or she would have under the same circumstances. The standard should be whether the domain expert believes that the behavior being observed represents reasonable behavior-behavior that representative soldiers, airmen, etc., could have generated under these circumstances.

In determining reasonableness of behavior, it is frequently necessary to infer the state of knowledge or the "belief state" of the individuals or units in question. In some cases, these inferences will be fairly straightforward; in other cases, it may be necessary to query the participants as to what they believed to be happening at particular points in time, what their intentions were, and so forth. The capabilities of Advanced Distributed Simulation (ADS) make this process far more feasible than it is in most simulations. One can use the ADS after-action review and replay capabilities to reconstruct a particular point in the engagement from a particular vantage point. An example would be taking crew members on a "flying carpet" ride, if necessary, to refresh their recollections and obtain the best possible information as to what they were thinking and planning at that time.

For validating the behavior of semi-automated forces (SAFOR), the process of interrogating commanders and crews to ascertain their intentions and belief states presents a different problem. In the currently fielded implementations of semi-automated forces, the missions and states of knowledge of SAFOR units are not captured, as their positions and weapons firing actions are. To determine the reasonableness of SAFOR actions, it will be necessary to make these elements externally accessible so that they can be captured and archived along with the physical state data. This capability seems feasible, and is currently planned for execution as part of the Modular SAFOR effort. It should certainly be a part of all future SAFOR development under any program.

On Measuring Validity: A Global View

Simulations can be validated only by comparison and the best comparisons, of course, are against reality. To learn whether training in a firing simulation transfers to live fire, one must compare the live fire performance of crews with different levels of simulator training. To measure whether experience with tactical simulators helps, one must measure the real performance of people with and without the simulated experience. Properly done, such measurements provide confidence in the value of the simulations.

It is well to remember that validity and accuracy are very different aspects of simulation. A little league ball player with hours of batting practice against a pitching machine will have a higher batting average in real play than one without access to a pitching machine. Pitching machine practice is valid even though it is strikingly different than batting against a real pitcher. Subjective tests of a simulation system such as "do the pictures look real," are irrelevant to validity. No one thinks that a clay pigeon looks anything like a flying bird, yet shotgun training against clay pigeons is clearly valuable. Psychologists have developed an objective methodology for testing validity. They know how to compare performance in simulated situations with performance in real situations. We should regularly exercise that methodology.

Such comparisons depend on having measures of performance, but because the measures are themselves abstractions, "objective" tests actually compare the results from two different abstractions. It has long been known to computer programmers that one cannot prove a program to be correct; one can prove only that two programs are equivalent. Similarly, the best validation we can do, short of war, tells us only that one simulation produces results consistent with the needs predicted by another. Consistent results build confidence that "stupid" errors have been caught. Consistency is a necessity even if not a sufficient condition for validity.

Validity itself is an elusive goal. Our best wisdom is required to hone our simulations to the point where we can entrust our future to them. Our trainees will learn to perform their simulated jobs; we must be sure what they learn in simulation will aid their ultimate performance. Our procurements will buy what our simulations predict to be best; and our future defense systems will reflect the flaws of our simulations, just as integrated circuits reflect the flaws in the design simulations used to develop them.

Experience suggests that it is easy to overlook important factors in a simulation. The present heavy emphasis on simulation begs for an appropriate level of investment in validity testing. This requires not only responsible analytic work to be sure that our simulations faithfully reflect what is most important but also great wisdom to be sure that we know what is important. We suggest that a portion of every simulation system procurement budget be devoted to validity studies, and that validity testing be a continuing part of the use of simulation.

XI. TECHNOLOGY ASSESSMENT

For each of the 12 DOD-driven technology areas, an assessment was made as to the relative maturity and the estimated level of activity underway. This latter estimate generally relates to current or anticipated DOD contract activity. Figure 12, "Technology Assessment, (DOD-driven Technologies)," depicts the technology assessment with a range of 1 to 5 used to suggest the maturity and activity of each technology. To provide justification for the level of activity score, we have cited some example programs and the sponsoring service or agency involved. The "Issues" column highlights some of the more prominent issues that various experts have brought to our attention.

Examining the Maturity/Activity Level column we made the following observations:

- Only one technology area (ergonomics) is deemed at level 4 maturity with the average for the remainder at somewhere between a 2 and 3.
- In many cases the maturity score is potentially of serious concern when coupled with a relative activity level of 1 or 2. This is especially true for key technologies such as Environmental Representation Models, M&S Construction (Authoring) Tools, and Computer Generated Forces (SAFOR, the semi-automated forces).
- The area of Protocols/Standards/Security is not only immature but also underfunded and in need of coordinated attention.
- The potential payoff (see Section IX, "Applications of Modeling and Simulation Technology to Engineering Design and Manufacturing") of more aggressive employment of M&S to engineering design and manufacturing strongly suggests that DOD should more aggressively fund this activity.
- In the fundamental technologies we believe that more effort is needed to adequately model cognitive behavior and military doctrine and tactics. Section VIII, "Application of Advanced Software Technology to Development of Computer Generated Forces," expands on this point as it relates to the current status of computer generated forces and the potential that artificial intelligence technology brings to that important area.
- In almost all the other technology areas the level of investment appears about right and the maturing to a level of three or four in the next few years is likely (see Section XII, "Technology Investment Considerations," for an expansion of this comment).

Figure 12
TECHNOLOGY ASSESSMENT
(DOD-Driven Technologies)

Maturity Score

1. Highly speculative
2. Understandably promising
3. Clear path to completion
4. Useable in demonstration systems
5. Mature - does not belong on the chart

APPLICATION UTILITY OF DOD-DRIVEN TECHNOLOGIES	MATURITY/ ACTIVITY LEVEL*		EXAMPLE PROGRAMS/SPONSORS	ISSUES
	Maturity	Activity		
LEVEL 0 - Fundamental Technologies				
• Human Behavior Representation Models				
- Cognitive behavior	1	2	• AI Labs: CMU, MIT, Stanford/ DARPA	Understanding and characterization group behavior, & complex decision making No rigorous military science and technology
- Military Doctrine and Tactics	1	1	• "Base of Sand" - Rand	
- Ergonomics	4	2	• Human Design Specification - Armstrong Labs • Virtual Reality - ARI	
- Environmental Representation Models				
- Weather/atmospheric effects	2	2	• SOFATS/USAF, ENVISION/DARPA • Radius/DARPA	• DIS Architecture must address Distributed Environmental Models
- Electromagnetic interactions	1	1	• Digits/DMA • Project 2851/USAF	
- Dynamic terrain representation	1	1	• CCTT/Atmy • BDS-D/Army • Project 2053B/DMSO	

Activity Score

1. Orphan technology – virtually unfunded
2. Some but inadequate funding
3. Present effort is acceptable
4. Well funded
5. Over funded

* *Maturity measured on a scale of 1 to 5, with 5 being a fully developed technology. Activity level measured on a scale 1 to 5, with 5 implying adequate investment.*

Figure 12 (Cont'd)
TECHNOLOGY ASSESSMENT
(DOD-Driven Technologies)

Maturity Score

1. Highly speculative
2. Understandably promising
3. Clear path to completion
4. Useable in demonstration systems
5. Mature - does not belong on the chart

APPLICATION UTILITY OF DOD-DRIVEN TECHNOLOGIES	MATURITY/ ACTIVITY LEVEL* Maturity	Activity	EXAMPLE PROGRAMS/SPONSORS	ISSUES
LEVEL 1 - Enabling Component Technologies				
• M&S Construction Tools - Terrain/Environmental Data Base Generation - Real-time Applications - Protocols/Interfaces - Validation/Verification	1	1	• DMSO Initiatives • Army/TEC Initiatives • STRICOM Initiatives at UCF/IST	• Critical for widespread employment of M&S • Needs more funding/ attention
• Instrumentation - Position/Orientation Transducers - Velocity/Acceleration Sensors - Actuators - Specialized Displays - GPS/ Digital Comm - Miles Sawe II	3	3	• MAIS/Army • Miles Sawe II/Army • ATD#l/DARPA	• Interoperability • Making greater use of existing tactical comm systems

** Maturity measured on a scale of I to 5, with 5 being a fully developed technology. Activity level measured on a scale I to 5, with 5 implying adequate investment.*

Activity Score

1. Orphan technology - virtually unfunded
2. Some but inadequate funding
3. Present effort is acceptable
4. Well funded
5. Over funded

Figure 12 (Cont'd)
TECHNOLOGY ASSESSMENT
(DOD-Driven Technologies)

Maturity score

1. Highly speculative
2. Understandably promising
3. Clear path to completion
4. Useable in demonstration systems
5. Mature - does not belong on the chart

APPLICATION UTILITY OF DOD-DRIVEN TECHNOLOGIES	MATURITY/ACTIVITY LEVEL* Maturity	Activity	EXAMPLE PROGRAMS/SPONSORS	ISSUES
LEVEL 2 - System Technologies				
• Instrumented Range Systems	2	4	• TCTS/Navy, JACTS/USAF MAIS/Army, ATD#l/DARPA	-Standard Architecture & Interface to DIS
• DOD Data bases	2	3	SOFATS/USAF, BDS-D/Army, Envision & Radius/DARPA	• Rapid, Accurate Generation • Reuseability
• DOD Protocols/Standards/Security	2	2	• DIS Architecture/STRICOM • OSF (Commercial) Initiatives	• Needs greater attention "borrow" MLS from intelligence community
LEVEL 3 -Simulation Applications				
• Manufacturing Process Simulations	2	2	• MMST/DARPA	- Mechanical lags semi-conductor
• Engineering Design Models & Simulation	3	2	• CSRDF/NASA Ames	- Costly to use/operate
• Manned Simulators	3	3	• ADST/Army, CCTT/Army Aircraft/All Services	• Displays & visuals need improvement
• Stochastic Wargaming Simulations	3	3	• ALSP/DARPA	- Too many non-interop models
• SAFOR	1	2	• CCTT/Army, ADST/Army	• Needs more attention - untapped potential

** Maturity measured on a scale of I to 5, with 5 being a fully developed technology. Activity level measured on a scale I to 5, with 5 implying adequate investment.*

Activity Score

1. Orphan technology - virtually unfunded
2. Some but inadequate funding
3. Present effort is acceptable
4. Well funded
5. Over funded

XII. TECHNOLOGY INVESTMENT CONSIDERATIONS

Current Levels of M&S Investment

Accurate estimation of current levels of defense research and development (R&D) investment in M&S technology has proven to be extremely difficult. The Defense Modeling and Simulation Office (DMSO) has reported to us that its effort to quantify the level of R&D investment in M&S has made little progress. This is due to a great deal of R&D funding being encompassed within major program procurements, and that the DOD cost accounting system is not designed to determine easily this funding component from Service funds earmarked for R&D, procurement, and support services.

The estimates of DOD investment in M&S provided for this report are therefore only rough estimates of known major M&S programs within the Services and government agencies. The portions of these funds dedicated for technology R&D can range widely from 10% to 80%, depending on the degree of production specified for the particular program.

Figure 13, "Estimated DOD Investments Ongoing in the M&S Community," summarizes some of the current and projected DOD M&S programs. In many of these major programs, such as the Army's Close Combat Tactical Trainer (CCTT) and SOFATS, there is a significant R&D component involving hundreds of millions of dollars to develop technologies in the areas of SAFOR and terrain and environmental representation models and databases.

Remaining Technology Challenges

Future investment in ADS technologies should be clearly targeted at areas in which significant technical challenges remain and are not expected to be addressed by investment from the commercial sector. We have identified several such areas that require immediate DOD attention so that they can be overcome in the next two to five years and thereby facilitate the advancement of ADS technology within the DOD community. These areas are scalability, SAFOR, M&S construction tools for ADS applications, protocols and standards, reusable environmental databases, multilevel security (MLS), and the individual combatant on virtual and constructive battlefields.

Scalability

We define scalability in terms of the ability to extend the scope and size of ADS technology to levels well beyond what is available today (see Section VI, "Architectural Challenges in Distributed Simulation"). In terms of numbers of objects and sensors, we foresee a need to develop the requisite technologies

Figure 13
ESTIMATED DOD INVESTMENTS ONGOING IN M&S COMMUNITY*

Agency/Service	*Program and Gross Dollars (in Millions)* Name	$M	*Comments*
DARPA		40 per fiscal year	• Does not include related initatives such as high performance computing, etc.
DMSO		76 (FY-93)	• Used to "seed" service programs and establish DOD-wide initiatives.
Navy	TCTS	300	• **Will develop a sophisticated ACMI** to upgrade existing Southwest **US ranges and to take to sea as ACMI** mobile range.
Army	BDSD	50/yr	• Was SIMNET, managed by STRICOM.
	CCTT	1000	• Contract to be awarded in Sep 1992. Represents a total over 5 to 10 years
	MAIS	90	• Treated as test and evaluation instrumentation.
	Miles Sawe	130	• Player units for training. New devices include GPS and Real-Time Communciations.
	AGES	120	• Air-Ground Engagement Systems
Air Force	JACTS	100 plus	• Major upgrade to Air Force Southwest Ranges to be awarded in FY-93.
	SOFATS	750	• A mission rehearsal and air crew training system. Develops seven major new simulators. Includes dollars for Army SOF Aviation.

These estimates are for major M&S initiatives which are or will shortly be under contract. The totals shown are estimates over the life cycle of the program and thus the dollars will be spent over several fiscal years.

that will increase the size of ADS exercises from the current level of 1,000 objects to 10,000 objects (one order of magnitude) by 1995, and to 100,000 objects (two orders of magnitude) by the year 2000. All indications are that these objectives can be achieved with a combination of incorporating the newest commercial networking and telecommunications technologies (e.g., ATM/SONET, the Synchronous Optical Network) along with specialized techniques to reduce network traffic (e.g., intelligent and adaptive multicast networks). These traffic reducing techniques are unique to DOD's needs and are not expected to be produced by the commercial sector.

Another aspect of scalability concerns increasing the number of types of objects. To date, this has not been a priority since the numbers of types of objects have been relatively low. However, as the ADS community continues to grow and add new object types to the network, configuration management will clearly become a significant problem in the next five years. The current process of creating and inserting new objects by manually upgrading software and databases on all simulation nodes on the network will clearly become unacceptable as the number of different types of objects grows. The challenge is to create a robust and well-designed automated methodology and process to allow any ADS node to create a new object and insert it into the virtual world for interaction with existing objects without requiring a system-wide software and data base upgrade. This technology solution can also only be effective if employed within a new kind of configuration management structure that is able to deal with a very large, complex, installed base of software and hardware distributed and supported by the many independent organizations developing ADS applications around the world.

Since a solution to this very complex problem involves protocol standards and significant changes to system architecture and management infrastructure, we feel that it is not too early to begin work in this area.

Semi-automated Forces

Semi-automated forces (SAFOR) are in their infancy and have a tremendous amount of untapped potential. Today, the state of the art in SAFOR systems is still relatively primitive in its level of intelligence, yet it has proven to be very powerful and effective in both training and development applications. The current SAFOR developed for the SIMNET program, for example, enables a single workstation to generate and run about 50 dynamic vehicles (both air and ground) in real-time, enabling us to run brigade-level exercises with 10 to 50 personnel, depending on the granularity level desired. While a commander can run and control a battalion from a single workstation, the level of "intelligence" exhibited by this configuration is less than one in which a battalion is manned as several company-level workstations.

We feel that SAFOR has significant room to advance in the area of vertical integration to extend its applicability to higher echelons, as well as horizontal integration to achieve more intelligent and complete representations of combat forces. The technical challenge is to develop the interactive algorithms to represent realistically human behavior for decision making so that a future SAFOR system, manned by only a small number of commanders, will be able to field and control on the battlefield a higher echelon force down to the granular level that is indistinguishable from one that is fully manned by crews operating individual vehicle simulators. In some sense, this could be regarded as a variation on the famous Turing test in computer science, in which the goal is to create an intelligent machine whose cognitive behavior makes it indistinguishable from one operated by a human during normal conversation.

To date, DARPA has been the primary investor in SAFOR technology development and has been funding its continued development at a relatively modest level. We feel that the very high potential payoff of this technology justifies a significant increase DOD investment to several times the current levels.

For more information regarding SAFOR technology, see Section VIII, "Application of Advanced Software Technology to Development of Computer Generated Forces."

M&S Construction (Authoring) Tools for ADS Applications

To date, the growth of the ADS user base has largely been constrained by the lack of trained ADS developers within the training and development communities. The current learning curve that new users must ascend is relatively steep (and correspondingly costly) which provides a barrier to entry into the ADS world. We feel that the availability of quality software tools to enable a new user to build ADS applications very quickly would greatly facilitate ADS acceptance and growth. In particular, we see the greatest needs for software tools in the areas of 1) rapid terrain and environmental data base generation, and 2) real-time simulation applications.

Some work in this area has been performed by Rand under DARPA and Army sponsorship.

Protocols and Standards

The current DIS protocol standardization effort is critical for successful implementation of interoperable, flexible DIS systems, and needs to be supported by DOD to the maximum extent possible. As the first generation of DIS-compatible systems come on line, we foresee the opportunity for extensions that will enable interoperability across the entire range of M&S applications. This effort, along with standardization in other areas such as terrain and environmental databases as well as visual system formats, is a key requirement for the widespread acceptance of ADS, and must be actively supported by DOD with participation and funding.

In addition to DIS, there are other types of protocols that will clearly be needed to fully exploit the value of distributed simulation and achieve the goal of a truly seamless synthetic environment bridging the virtual, constructive, and live worlds. For instance, the Aggregate Level Simulation Protocol (ALSP) developed by DARPA has demonstrated some techniques to address problems in the area of time management when linking time-driven, synchronous real- time virtual simulations with event-driven, asynchronous constructive wargaming simulations. The current proposals to link the instrumented live ranges in the southwestern United States to permit interoperability and joint Service operations have highlighted new problems regarding communications constraints unique to the live ranges that have implications on the protocols that are not currently addressed by DIS. A technical problem is the linking of engineering-level simulations with virtual simulations, an area that is currently being addressed by the Joint Modeling and Simulation System (JMASS) program office in coordination with the DIS community.

We feel the significant commonality in these discrete protocol areas warrant attention by DOD to coordinate these efforts so as to maximize their utility for the M&S community across all of DOD. It is a key issue that needs to be addressed in order to fully realize the goal of a truly seamless synthetic environment.

Reusable Environmental Databases

The requirements for environmental databases have been rapidly increasing as the user community expands its use of ADS technology to cover a wider variety of applications. One of the most important classes of these databases are terrain databases for use in simulation systems. The DOD, largely through the efforts of the Army's Topographic Engineering Center (TEC), has made significant progress in terrain data base generation technologies to incorporate high performance computer workstations for semi-automated terrain data base compilation from a wide variety of data collection sources, including satellite and reconnaissance photoimagery and Defense Mapping Agency (DMA) archives. In spite of these significant advances, the TEC reports that more and more DOD programs are demanding accurate and timely spatial databases, with rapid construction times that clearly indicate the need for higher levels of automation than that which exists today. Perhaps the most demanding of applications are those for mission rehearsal, which require very short lead times and very high accuracy and level of detail feature resolution. Other types of environmental data that require integration with the terrain databases include weather and atmospheric effects.

It is apparent that most standard commercial digital mapping products available today provide only basic capabilities and are insufficient to meet the demanding needs of the DOD M&S community. It becomes clear that DOD must continue to accelerate its initiatives in this area in order to prevent data base availability and quality from becoming a constraint on growth and acceptance of ADS technology in the DOD user community.

It is furthermore apparent that a significant investment has already been made by DOD in M&S databases of all varieties. Most of these databases have different formats and are only used by their local DOD communities. In many cases, they are not even known to exist by the rest of the DOD. The reason for this is not because the data is proprietary, but rather that there is currently no infrastructure to support DoD-wide data base standardization and storage, so that access to this information can be gained by interested users. We feel that it is in DoD's interests to-establish just such an infrastructure to provide a centralized, network-accessible repository for these existing databases, and to establish a set of standardized formats for new databases to facilitate their reusability by users across the DOD.

Multilevel Security

One potential major impediment to widespread employment of ADS within the combat development community is the availability of multilevel security (MLS) systems to enable distributed simulations involving classified data to be run on the network. The intelligence community within DOD has considerable experience in MLS and has invested significant funds to develop a number of these accredited systems for its intelligence applications. It is likely that a great deal of this existing MLS technology can be effectively employed for ADS applications at relatively low cost for modifications, rather than develop a entirely new system that would require accreditation. Some R&D investment would be required, for instance, to rehost some MLS software which runs on the VAX/VMS environment to the open-architecture UNIX environment favored by the ADS community.

This investment would be significantly less than developing the MLS technology from scratch, and would greatly increase the capability of ADS, facilitating its rapid growth and acceptance.

Individual Combatant on Virtual and Constructive Battlefields

To date, almost all DOD simulators have been vehicular-aircraft, armored vehicles, and ships. Even constructive simulations-models of war-fall far short of validly describing individual behavior in combat. Today there is no adequate simulation for individuals who fight on foot. Hence, synthetic battle environments reliant on virtual or constructive inputs are deficient in that they fail to account for key dismounted contributors to battle outcome, and live simulations are handicapped for lack of means to interface dismounted combatants with data from virtual and constructive simulations. Further, constructive models and simulations are deprived of the dense, reliable data that could be generated by properly instrumented individuals under combat-like stress performing on synthetic battlefields.

The technical challenges involve innovations in the following areas:

- Audio/visual stimuli. Provide real-time, positionally rational visual inputs via icon injection into ocular-protection or night vision goggles, helmet-mounted displays, and virtual domes. Also provide audio data from helmet mounted or in-ear speakers.
- Physiological tracking. Ascertain posture, musculo-skeletal response, ocular slew rates, vital signs, and other relevant data via on-person sensors and monitors.
- Environmental bounding. Indicate personal contact with objects in virtual environments--e.g., terrain, buildings, tree, boulders-via exoskeletal, motion-limiting, computer-linked interfaces (platforms, robotic arms, treadmills, etc.)
- Processing and communications. Provide an on-person, DIS-compatible interface with constructive or virtual simulations.

These technical challenges are expected to push the limits of the state of the art in microinstrumentation components and systems to overcome limitations in small size and weight power sources, close-to-the-eye displays, heat dissipation techniques, and robotics.

XIII. OBSERVATIONS AND RECOMMENDATIONS

Observations

On Commercial Computing Today

Computer technology comprises two facets, hardware and software. Hardware alone is unable to do anything, and software by itself is useless. Only in combination can powerful hardware and well-crafted software provide the awesome capability of modem computing.

The course of today's computing industry is guided largely by the need for this union. The availability of personal computers created a commercial market for software to serve the needs of a vast number of consumers. The availability of this software has in turn created an increased demand for hardware that can run that software. The vibrant market thus created pushes technology forward at a pace without peacetime precedent.

Because of the widespread use of personal computers we have come to think of computing as an inexpensive commodity. It is not. The cost appears low only because the multimillion dollar development cost of a new computer system supports sales of many hundreds of thousands or millions of computers, resulting in consumer costs of only a few thousand dollars each. Similarly, the multimillion dollar development cost of a new software product can be shared over many sales to result in software costs of only a few hundred dollars a copy. The low cost of computer hardware and software comes about because of the large market volume.

It remains true that with computers almost anything is possible but nothing is easy. The complexity of both modem hardware and particularly of modem software continues to present a major challenge to system developers. The industry is full of tales of hardware systems whose development schedules have slipped, and of even more tales of similarly late software products. It's hard and costly to make computer systems work. The fact that they work in large numbers and serve unsophisticated users is a high technology indeed.

A third facet of computing is data. Simulation always depends on data. In the case of simulations involving motion over a land mass, a representation of the topography, ground cover, and cultural features of the land is required. In the case of simulations involving physical phenomena, raw data about the physical principals and the boundary conditions are required.

Collecting, updating, and correcting this body of data is a continuing chore.

DOD has already collected a huge body of geographic data. This data is of great value to DOD now: it is the basis for our maps, it guides our cruise missiles, it supports both military and commercial shipping, and it is the geographic input for our simulations. Collecting this data has been a vast enterprise whose importance will continue for the foreseeable future. Even though much is known, there remain great gaps in this data. Interpreting the raw sources to capture the cultural features is a continuing task.

This body of geographic data will come to have increasing commercial significance. Increases in commercial use of simulation for training, education and entertainment will need this kind of data. One can imagine a day in which every automobile carries a Global Positioning Satellite (GPS) receiver and a large geographic data base. DOD should collaborate with such efforts so as to be able to convert the resulting systems directly to DOD uses. Without DOD help, such systems may be useful only within CONUS (Continental United States), or otherwise not serve a larger DOD need. We have the chance to stimulate this sort of commercial development by supporting it with our data. The ultimate returns to DOD from such a collaboration will be large.

Qn Defense Use of Computing for Simulation

The DOD has recognized that the computer art may now permit wide spread use of computer-based simulation. Simulation by computer is in common use in engineering applications from stress analysis to the design of computers themselves. Large computer simulations of objects that look almost real are common in TV advertising and are beginning to appear in feature films. For some time flight simulators have been used for pilot training as being both safer and more economical than actual flight. The success of SIMNET as a demonstration of distributed simulation is also encouraging.

The attraction of using more modeling and simulation in defense applications, of course, is that it will provide better readiness at less cost in both training and procurement. One can imagine a future in which the amount of training provided to our troops is increased manyfold through the use of computer simulations. The cost of that training is vastly reduced because the only support required will be for the computers and the tiny amount of electric power that they consume. In that same future, one can imagine that defense procurements are guided by the results of battle simulations that show which weapons systems and which tactics prevail so that procurements are more effective. Simulation can reduce the technical risks and the potential for schedule delay in defense systems acquisitions.

There are two problems associated with using more simulation in defense applications. The first is cost: can we obtain adequate equipment and software to do the desired task? The second is trust: can we trust the results of simulations to tell us what to buy, and can we trust simulated training as adequate for meeting the tests of actual combat?

We have focused on the second of these problems, that of trust, in Section X, "Verification, Validation, and Accreditation." In this section we will focus on the cost question. Is it now practical for DOD to embark on a program of heavy emphasis on simulation?

On the Cost of Simulation Systems

In the forecast of commercial technologies (Section III) we noted that the number of simulation capable computing platforms will increase enormously between now and the end of this century. This growth in number of systems will be fueled technically by increases in computing power stemming from improvements in the basic integrated circuit technology. These systems will be used for applications in entertainment, education, and technical simulation. Thus our recommendations on computing hardware suggest that DOD leam better how to draw from commercial offerings and avoid unique procurements.

A crucial part of every simulation system is the software that makes it perform. There will be commercial developments here also, but they will lag behind the hardware developments on which they depend. DOD will have to make major investments in the software for its simulation systems. Some of this software will be DOD unique, and thus must be DOD supported. Some of it might appear without DOD support, but DOD support will make it available sooner. DOD support will serve not only DOD needs, but also speed up the use of simulation in industry. We expect that many of the ideas used first for DOD simulation will transfer to commercial use for entertainment and education, and in turn support a better industrial base from which future DOD systems may draw.

A particular leverage point here is software tools for simulation. DOD can profit by using tools developed by industry for animation in advertising and entertainment. An example is the development of realistic dismounted troops for use in training and tactics simulations. DOD can also collaborate with the makers of such tools to make better ones that DOD needs. For example, the task of generating objects for computer display, the task of animating human figures, and the task of applying digital imagery to simulation purposes are all common to both DOD and the entertainment industry. We look to see a collaboration between DOD and a group of suppliers not now involved in DOD efforts.

On Advanced Displays

The workhorse display system for the past 50 years or more has been the Cathode Ray Tube (CRT). This technology has proven to be less costly than others and reliable enough for many applications. The use of CRTs in television has, of course, put many types of CRT into very large scale production and thus has reduced their cost dramatically.

Industry has been seeking an alternative to the CRT for many years. Flat panel displays are beginning to be used in many lap-top computers because of their more favorable shape factor. They suffer from brightness, weight, and ruggedness limitations, however, which may make them less useful for DOD applications. Other promising display alternatives appear to be available.

One promising new class of displays called "virtual image" displays are distinguished from ordinary displays by size and use. Where one looks at an ordinary display from a distance of a foot or more, one looks into a virtual image display, holding it up close to the eye. Because virtual image displays are held close to the eye they can be smaller, lighter, and are potentially less expensive than ordinary displays. It appears possible to make virtual image displays with very high resolution at potentially low cost.

Several potential ways to make virtual image displays are available, some developed with DOD support. Light valves, vibrating mirrors, moveable mirrors on integrated circuit scale, and frequency doubling lasers may all play a role in such displays. DOD can have a very important effect on bringing these underlying technologies to fruition.

DOD has many unique requirements for high quality displays with unique shapes. Strap-on displays for use in the field, e.g., on tank periscopes, are but one such application. DOD should maintain a vigorous program in developing new and improved displays.

Recommendations

Computing Hardware

The commercial sector will produce the raw computing power required for DOD simulation. Project life cycles will be short; we can expect improvements in performance on an annual basis, with much equipment becoming obsolete in about three years time.

(1) DOD must learn to procure this commercial equipment in a timely way at low commercial prices.

Simulation Scalability

Projected needs for advanced distributed simulation imply large increases in the numbers, types, and level of detail of the objects represented in the simulations (see Section VI, "Architectural Challenges in Distributed Simulation"). Significant architectural modifications will likely be required to accommodate these scale changes. For example, all information might not be sent to all nodes anymore, centralized servers might be needed to generate computationally intensive environmental information and send it to nodes on an as-required basis, and simulator designs that allow a rapid and automated update of weapon system representations held by the simulator might be required.

(2) DOD should give high priority to ensuring that an overall architecture that will readily accommodate large increases in simulation scale is being developed. This architecture should evolve- from the current architecture for distributed simulation, but most likely will extend well beyond it.

Computer Generated Forces (Semi-automated Forces)

Additional effort is needed in the development of software to represent automated forces. The three key areas for research are integration of improved functional capabilities, timely construction of automated forces and real-time intelligent performance. See Section VIII, "Application of Advanced Software Technology to Development of Computer Generated Forces," and Section XII, "Technology Investment Considerations," for further details.

(3) DOD, and DARPA in particular, should increase the modest funding in this technology area because there are significant gains to be realized.

Data Bases

The data bases used in DOD simulations will be collected and maintained at considerable expense to DOD. These data bases are themselves of substantial value. Additional research is needed to develop more automated techniques to create rapidly data bases to include landmass representation, weather and atmospheric effects. See Section VII, "Synthetic Environments," and Section XII, "Technology Investment Considerations," for further elaboration.

(4) DOD must continue to accelerate its initiatives in data bases in order to prevent data base availability and quality from becoming a constraint on growth and acceptance of modeling and simulation in the DOD user community.

Verification. Validation and Accreditation NV&A)

The important task of verifying, validating, and accrediting battlefield behavior, modeled in some form, should receive greater attention in all DOD M&S programs.

(5) Procedures, standards, and measures of performance need to be developed to guide and support VV&A processes. Section X, "Verification, Validaion, and Accreditation," elaborates further on this topic.

Construction Support Tools

Software will continue to be a major expenditure for DOD simulation. DOD can ameliorate the high cost of software by supporting efforts aimed at better software engineering practices and by developing construction (authoring) tools that will enable users to build applications quickly and accurately.

(6) DOD should continue its support of software engineering techniques in general, and the development of construction support tools in particular.

Standards

Large systems pose problems not encountered in smaller ones. DoD's plans to use distributed simulation will generate systems whose management will itself require careful work. Strong efforts will be required in message and interface standards, in configuration control and distribution of software and support data, and in the graceful degradation of performance in the face of equipment failure. Properly done, these standards will outlive any particular generation of equipment and software. The process to date on the DIS architecture and standards is very encouraging.

(7) DOD should support a vigorous effort on simulation standards and configuration management.

Security

Both DOD and industry need to protect information from unauthorized disclosure and to operate systems at multiple levels of security. DoD's expertise in this area stems from years of expensive efforts which must be continued. The best of this work is held in the intelligence community and is not widely available at this time. So far we have (by active and passive DOD efforts) denied our best information on security to the U.S. industrial base.

(8) DOD should collaborate with industry to develop secure computing systems suitable to both industrial and military use. The M&S community should visit the DOD intelligence community to acquire developed and accredited multilevel secure systems.

Computer Image Generators (CIGs)

The commercial sector will produce digital computer image generators for applications in education, science, engineering, and entertainment. These image generators will be adequate for most, if not all, defense applications.

(9) DOD should buy what is commercially available for CIGs.

Displays

Although development of CIG systems is adequately funded by industry, there remains a need for better displays. DOD's requirements for displays that are light in weight, portable, rugged, and of high resolution are greater and earlier than those of industry.

(10) DOD should support advanced work in display technology including miniaturized displays and head mounted displays.

New Initiatives To Fill Voids

The DOD should invest in three new initiatives: (1) virtual simulation support for the individual combatant; (2) the combination of some live-constructive-virtual simulation interactions; and (3) the development of simulation support tools for logistics, medical, maintenance, and other military support functions.

(11) DOD must invest in these new initiatives to respond to needs in these areas which modeling and simulation can fulfill.

LIST OF ACRONYMS

A/D/A	Analog/Digital/Analog
ADS	Advanced Distribution Simulation
ADST (STRICOM)	Advanced Distribute Simulation Technology (Program)
AFB	Air Force Base
AGES	Air-Ground Engagement Systems
AH-64	Army attack helicopter
ALSP	Aggregate Level Simulation Protocol
ARI	Army Research Institute
ASIC	Application Specific Integration Circuits
ATD	Advanced Technology Demonstration
ATM	Asynchronous Transfer Mode
AWACS	Airborne Warning and Control System
BDS-D (Army)	Battlefield Distributed Simulation Development
CAD	Computer-aided Design
CAE	Computer-aided Engineering
CCTT (Army)	Close Combat Tactical Trainer
CIG	Computer Image Generator
CIM	Corporate Information Management
CMOS	Complementary Metal Oxide Semiconductor
CMU	Carnegie Mellon University
CONUS	Continental United States
CRT	Cathode Ray Tube
CSRDF (NASA)	Crew Station Research and Development Facility
DARPA	Defense Advanced Research Projects Agency
DBMS	Database Management System
DIS	Distributed Interactive Simulation
DISN	Defense Information Systems Network
DMA	Defense Mapping Agency
DMSO	Defense Modeling and Simulation Office
DOD	Department of Defense
DRAM	Dynamic Random Access Memory
DSB	Defense Science Board
DSI	Defense Simulation Internet
DSP	Defense Support Program; Directory System Protocol

ENVISION (DARPA)	a DARPA software initiative
FDDI	Fiber Distributed Data Interface; Fiber Optic Digital Data Interchange
FMS	Foreign Military Bases
gbit	gigabit or 10^9 bits
GIS	Geographical Information System
GPS	Global Positioning Satellite
I-IOTAS	Hands on Throttle and Stick
IADS	Integrated Air Defense Simulator; Interactive Advanced Distributed Simulation
IC	Integrated Circuit
IP	Internet Protocol
IPP	Integrated Product/Process
IPPD	Integrated Product/Process Development
JACTS (USAF)	Joint Aircrew Training System
JIT	Just-in-Time
JMASS	Joint Modeling and Simulation System
JPO	Joint Program Office
JSTARS	Joint Surveillance Target Attack Radar System
LAN	Local Area Network
M&S	Modeling and Simulation
MAIs (Army)	Mobile Automated Instrumentation Suite
mbit	millions of bits
MIPS	millions of instructions per second
MIT	Massachusetts Institute of Technology
MLS	Multilevel Security
MMST(DARPA)	Microelectronics Manufacturing Science & Technology
MPP	Massively Parallel Processor
msec	millseconds or 10^{-3} seconds
NASA	National Aeronautics and Space Administration
OSF	Open Software Forum
PDU	Protocol Data Unit
pix/sec	pixels per second
plysl/sec	polygons per second
R&D	Research and Development
S&T	Science and Technology
SAFOR	Semi-automated Forces
SCUD	a short-range ballistic missile

SIMNET	Simulator Network
SOF	Special Operations Forces
SOFATS (USAF)	Special Operations Forces Aircrew
SONET	Synchronous Optical Network
SPECmarks	benchmark standard for evaluating computer performance
STRICOM	Simulation, Training, Instrumentation Command
SW	Software
T/20	the communications gateway in SIMNET
TCTS (Navy)	Tactical Combat Training System
TEC (Army)	Topographic Engineering Center
TES	Tactical Engagement Simulation
UAV	Unmanned Aerial Vehicle
UCF/IST	University of Central Florida/ Institute far Simulation and Training
USAF	United States Air Force
VLSI	Very Large Scale Integrated Circuit
WAN	Wide Area Network
WISSARD/IFOR	automated forces development program in DARPA

APPENDIX B:

DEMONSTRATIONS AND EXPERIMENTS

DEMONSTRATION AND EXPERIMENT SUMMARY (EXPECTATIONS/SIGNIFICANCE)

Serve Demanding Warfighting Customers

1. JTF campaign planning and training (improve joint capability)
2. Interactive exercise at home stations (previously impractical)
3. Integrated National Guard Brigade Training (previously impractical)
4. CINC wargaming networking (new capabilities from existing systems)

Transform the Process

5. Combined arms C2 (evaluate new concepts)
6. Theater air and missile defense (evaluate new concepts/technology)
7. Suppressing critical mobile targets (new capability from existing systems)
8. Networked battle games (new capabilities from commercial systems)
9. Battlefield visibility (evaluate new concepts/technology)

Integrate Functional Stovepipe

10. Network training and test ranges (previously impractical)
11. Realistic electronic combat test and training (previously impractical)
12. Improving warfighter C4I interface (new capabilities from existing systems)

DEMONSTRATIONS

Vision \ Demonstration	JTF Campaign Planning & Training	Interactive Exercise at Home Stations	Integrated National Guard Brigade Training	CINC Wargaming Networking	Combined Arms C2	Theater Air & Missile Defense	Suppressing Critical Mobile Targets	Networked Battle Games	Battlefield Visibility	Networtk Training & Test Ranges	Realistic Electronic Combat Test & Training	Improving Warfighter C4I Interface
Improve Training Readiness	√	√	√	√						√	√	
Create a Joint Environment	√	√	√	√			√			√	√	√
Transform Support to Acquisition	√				√		√			√		√
	Serve Customer				Transform Process					Combine Benefit		

DEMONSTRATION #1: JOINT TASK FORCE OPERATIONS IN SW USA

OBJECTIVE. Exercise Joint Task Force battle staffs in the Southwestern United States.

WHY? Our forces can do fragmented pieces of JTF campaign planning and training today. But, they are unable to involve multi-service planners and operators often enough, or on the scale requisite, for foreseeable contingency operations. Instead, they have relied upon ad hoc arrangements to meet contingencies as they develop. For the future, they need arrangements that facilitate repetitive, short notice JTF exercises in which each JTF commander and his staff can be exercised in campaign planning, task order preparation, and communication and evaluation of results.

WHAT? This demonstration will network existing SW USA training and testing facilities of the several services under a JTF to provide for regular battle staff training in a realistic environment. It seeks to add virtual and constructive simulation to that live simulation, enhancing its effectiveness without interfering with attainment of its objectives.

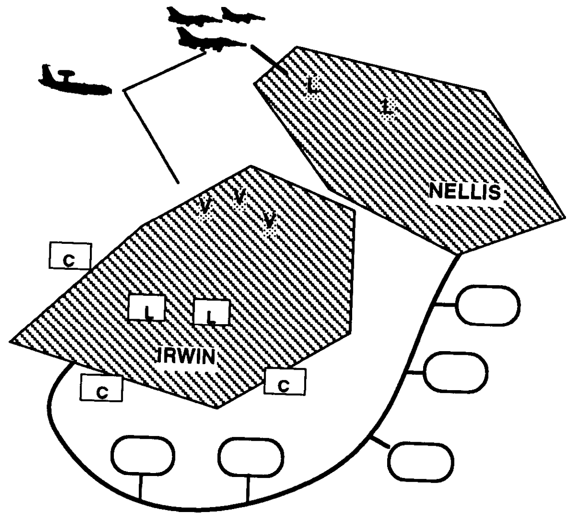
BENEFITS. The new technology will enable:

- Extending the perception of the units actually present of adjacent and supporting friendly units, and of an opposing force deployed in depth, represented by live and virtual elements.
- Incorporating national and theater intelligence inputs, to be evaluated against outputs in targets for prosecution, or in post-strike assessment.
- Providing for attacking targets geographically off-set from where they were located by intelligence, so that striking units can exercise against the most advantageous available simulation of target and defenses.

Demo #1 : JOINT TASK FORCE OPERATIONS IN SW USA

- ***Objective:***

  Conduct series of Advanced Technology Demonstrations of joint training overlayed on Service training at SW USA live ranges. In 1994:
  - Internet the several Service ranges and a JTF [CVBG/Air Division/Army Division/Marine MEB] supported by the Joint Warfare Center
  - Without interfering with Service training, provide a synthetic environment in which units actually present perceive themselves operating in the context of the entire JTF and against an enemy force represented by live, constructive, and virtual elements
  - Exercise NTM and theater broad-area sensors [live and virtual]; evaluate from target prosecution and post-strike damage assessment
- ***Why?***
  - Short-notice JTF exercises
  - C4I interoperability to execute-level
- ***Benefit:***
  - Demonstrably ready joint forces
  - Reusable, up-gradable simulation components
  - Data for M&S improvements



DEMONSTRATION #2: INTERACTIVE EXERCISE OF SUPPORT ELEMENTS AT HOME STATIONS

The objective of this demonstration is to provide a virtual simulation environment that will enable support elements (such as, intelligence, logistics, etc.) to participate as an integral part of large scale exercises on a realistic and interactive basis. The virtual simulation environment will consist of distributed systems located at home stations.

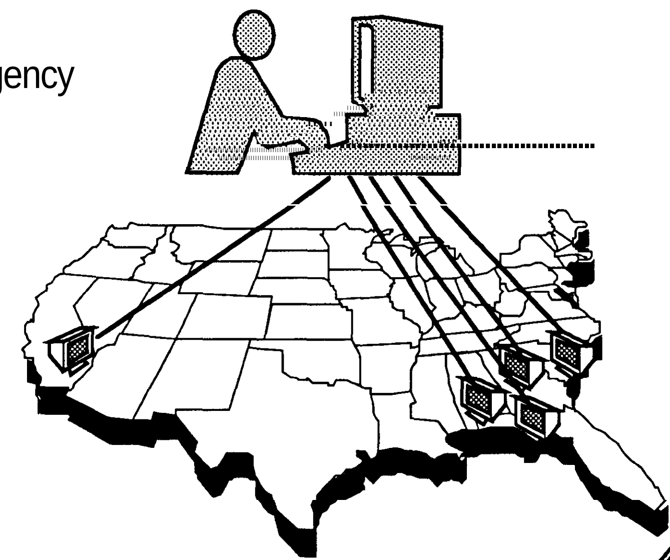
Currently, support elements are not interactive during large scale exercises. Instead, support assumptions are made or the data is examined off-line, after the fact, and generally with little impact on the "real" results. Consequently, erroneous end game results can be concluded. For contingency operations, where lead times are typically short and support element response times critical, it will be essential that support element interactions be clearly evaluated and understood. By providing a distributed simulation at each home location the support participation can be on a regular basis. Additionally, the cost of physical relocation will be eliminated.

The demonstration will develop a distributed simulation testbed to enable support element participation in large scale field exercises or wargames. The support simulation will account for real time motion of forces, equipment/personnel losses requiring refurbishment/repair/replacement and replenishment of consumables. The ability of the support elements to respond to these requests will be measured and quantified. In like manner, the intelligence support will be able to change and update intelligence data to the CINC battle staff thereby making the wargame far more realistic.

The benefits of the demonstration include more realistic large scale field exercises and wargames, regular and interactive participation of support elements, and an improved contingency response capability.

Demo #2: INTERACTIVE EXERCISE OF SUPPORT ELEMENTS AT HOME STATION

- ***Objective:***
  - Provide for regular, realistic, interaction of support elements (intelligence, logistics, etc), with command elements using distributed virtual simulations at home stations.
- ***Why?***
  - Current approach to exercising CINC battle staff is either large scale field exercises - now too expensive and environmentally difficult - or wargames.
  - Use of intelligence assets not played in a way that regularly trains either customer or supplier.
  - Support elements assumed or examined off line - not interactive during exercise/wargame.
  - Support element responsiveness more critical in contingency situations.



- ***Benefit:***
  - Improved contingency response capability through frequent, more inclusive, interactive exercise of command, support and intelligence elements.

DEMONSTRATION #3: INTEGRATED NATIONAL GUARD BRIGADE TRAINING

OBJECTIVE. Increase the efficiency of pre-mobilization training in combat arms units of one or more National Guard Brigades designated for early mobilization for contingency operations.

WHY? During DESERT SHIELD/STORM, certain combat arms units of the National Guard were deemed deficient in training readiness, to lack significant amounts of individual and small unit training. Their deployment to Southwest Asia was postponed until they remedied these shortfalls, occasioning a continuing controversy. Ameliorative action has been mandated by Congress, including allocations for applications of ADS to improve pre-mobilization training. At issue, therefore, is the efficient use of training time, and accountability for individual and collective training achievements. Also at issue is the locus of training, in that while security and maintenance dictates pooling armored fighting vehicles (AFV), that practice necessitates training time lost transporting troops to their AFV.

WHAT? The demonstration would apply ADS for AFV crew training, each in its own armory. Proposed are SIMNET-derived fully task trainers for each crew position, built around affordable, networked, NDI graphic work stations. This configuration would have the advantage of being upgradable as more powerful, less expensive workstations become commercially available. Further, this virtual simulation would be networked with constructive simulation for battle staff training (e.g., JANUS), and with the oncoming RCAS for record-keeping of performances.

BENEFITS. Use soldier-time for training, and assure him and his unit commander that he will get credit for acquired skills and knowledge upon mobilization.

Demo #3:
INTEGRATED NATIONAL GUARD BRIGADE TRAINING

- *Objective:*

-Introduce ADS to increase the efficiency of pre-mobilization training in combat arms units of one or more National Guard Brigade.

-Adapt SIMNET for use in armories for combat vehicle crew training via affordable, networked graphic work stations, configured as full task trainers for each crew position.

-Use constructive simulation (e.g., JANUS) for battle staff training.

– Net the ADS applications into the Reserve Component Automation System(RCAS), now being deployed, to record training performances.

- *Why?*

-Most Guard soldiers lack means to acquire and to maintain individual and collective skills at their home armory, and consume valuable drill time traveling to remote training sites.

-Current training records are neither comprehensive nor accurate.

- *Benefit:*

-Optimal use of training time, and accurate estimates of training readiness upon mobilization.

DEMONSTRATION #4: CINC WARGAMING NETWORK

This demonstration is designed to show the DOD senior leadership the benefits of an internetted wargaming capability. At present, the Department lacks the capability to provide senior leadership with training and education that is both realistic and readily accessible. This inhibits effective joint development and assessment of contingency plans presently conducted by individual Service and CINC staffs. Demonstration objectives are to link current wargaming centers to a National Command Authority (NCA) location and to combine Air Force Blue Flag exercise and Joint Warfare Center control elements to form a single full-time control node.

The need for this capability is underscored by the urgent need to be able to shift planning and force development to a regional contingency basis. Unless wargaming centers do become networked, results of wargames will likely lead to divergent concepts, doctrine and lessons learned. The network demonstration would attempt to leverage continuing investment in Service and CINC wargaming activities to provide the synthesis necessary for joint understanding. Including a NCA node in the network provides a rapid response capability for contingency plan development and refinement.

The demonstration entails no significant development risk. The Distributed Interactive Simulation (DIS) network and microwave network exist. However, procurement of intelligent gateways for information interface would be necessary.

Finally, it should be emphasized that the potential benefits of this capability could be compromised without clear management responsibility.

Demo #4: WARGAMING NETWORK

- ***Objective:***

  Provide the Department of Defense regular senior level training and education, and a system to build and assess contingency plans by:

  - Networking wargaming centers to include a National Command Authority location.
  - Combine Blue Flag and the Joint Warfare Center as the full-time control node.

- ***Why?***

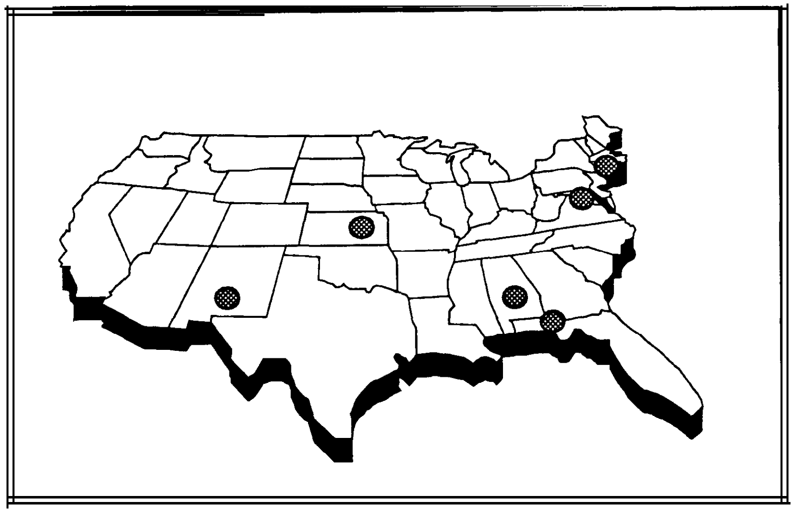
  - Leverage the continuing investment in Service and CINC wargaming actitivites

    Absent connection, results of wargames are likely to lead to divergent concepts, doctrines, and lessons learned.

- ***Benefit:***

  Provides joint understanding, concepts, doctrines, and assessments that leverage current and developing capabilities.

  Provide a rapid response capability to develop and assess contingency plans.



DEMONSTRATION #5: SITUATIONAL AWARENESS IN CLOSE COMBAT

OBJECTIVE. The objective of this demonstration is to provide accessible, easy to employ, interactive, network opportunities for the joint situation awareness in the close battle. The initial focus will be to determine requirements and implementation for shared situational awareness among engaged forces of all three services by virtual prototyping of command and control information flows and displays. The enabling requirement will be to network selected ground combat elements and close air support units (to efficiently exercise the close battle. Once connected, semi-automated opposition forces (SAFOR) can be included to add challenge and depth to the virtual prototypes. This kind of demonstration is a key element of DOD Science and Technology Thrust #5, Advanced Land Combat and is addressed in the Army's program titled Combined Arms Command and Control.

WHY?: The frequency and intensity of the joint execution of the combined arms battle will provide for skill refinement and joint doctrine development. Real time force synchronization of ground maneuver units (battalions and below) with air assets is extremely critical to successful close battle execution. Integration of all fire supporting arms assets by the ground commander into his scheme of maneuver is a very challenging skill that can be more efficiently addressed by networked virtual reality. If it is assumed that the ground commander will be outnumbered, the employment of air and supporting arms assets in the close battle is of heightened importance. The refinement of skill and doctrine along with real time situation awareness will greatly reduce the potential for fratricide. Equipment improvements will be identified and evaluated during the process.

WHAT? The demonstration would link geographically dispersed elements of the joint combined arms team. Crews in their respective platform simulators would be networked into a synthetic battlefield which will emphasize the close battle

Benefits.

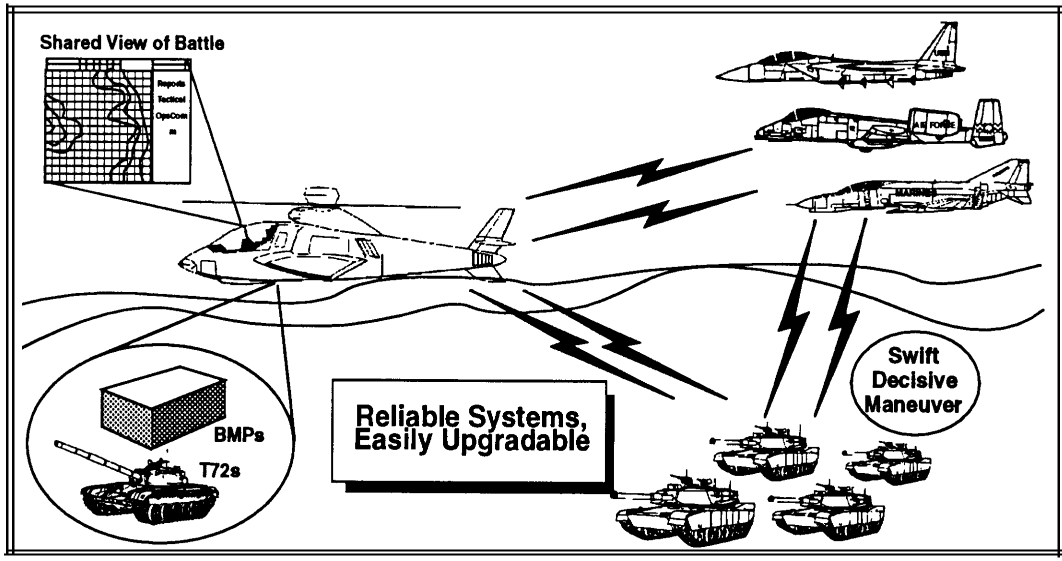
A. Early and continuing joint user insights will enable rapid convergence of acquisition and development to optimize weapon systems and provide opportunities to upgrade current platforms to provide real time shared situational awareness.
B. Performance in the joint execution of the close battle will be improved.
C. The integration of Close Air Support (CAS) into the combined arms battle will be significantly enhanced.
D. The increased frequency of joint combined arms team exercises will decrease the potential of fratricide through improved skills, doctrine and equipment.

Demo #5:
COMBINED ARMS COMMAND AND CONTROL (CAC2)

- ***Objective:***
  - Develop and demonstrate the hardware and software required to share threat and friendly situation, including combat identification systems inputs, target handoff and standard reports between elements of the mounted maneuver forces at battalion-level or below.

- ***Why?***
  - Shared situation awareness
  - Automatic self and friendly location

- ***Benefits:***
  - Reduced fratricide
  - Reduced decision timelines
  - Rapid force dispersion while massing fire



DEMONSTRATION #6: THEATER AIR AND MISSILE DEFENSE

Elements of the Simulation

Elements of the simulation must include the Patriot and THAAD systems, including all sensor systems, missile weapons, and control and communication stations, and linkages between these systems. Also included could be simulations of other systems that might provide important sensor warning indications, such as DSP/FEWS, JSTARS, ASARS, and National Technical Means. Sea-based defensive missile systems should be included. Existing and new communications and data links between all these systems and the theater commanders, including appropriate security considerations, should be evaluated. New threats, including low-observable missiles at all altitude, need to be considered, as well as wide range of terrain and sea-based simulation scenarios. jamming and disruptive actions by other threat forces, as well as terrorist activities, should also be considered for simulation.

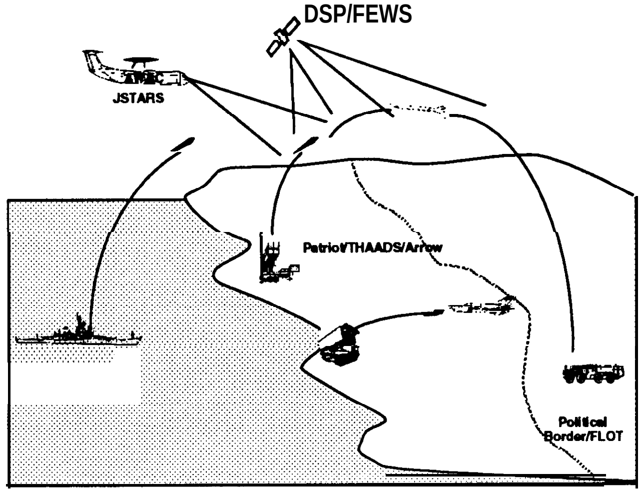
Structure of the Experiment

A major element of the experiment involves finding the targets, launching a coordinated attack,and killing the incoming missile targets, with damage assessment. Timelines for decision making and systems automated responses must be measured and evaluated, indicating the ability of being able to use collateral data from other sources within time-decision windows. A broad matrix of sensor and intelligence inputs should be evaluated by human operators in a mission context, against a wide range of threat types and attack densities and severity (numbers, cleverness of tactics, threat use of intelligence, etc.). The impact of new technologies, such as new sensors, improved processing for accuracy and speed, and graphical displays for decision making should be assessed. Also, the capability to accept intelligence inputs from other human operators such as pilots, ground observers, etc. as cueing inputs for the missile defense system should be considered, as well as the needed interfaces with other theater Service mission elements. Simulated coordination with mission planning of other air and ground forces, to understand the impact of both the incoming threats and the TMD response on other military actions, must be accomplished to determine the “real-time” requirements.

Demo #6: THEATER AIR AND MISSILE DEFENSE

- ***Objective:***
  - Provide early operator involvement in evaluation and integration of evolving theater air and missile defense capability.
  - Develop simulation and virtual environment to ensure timely validation of doctrine and tactics for early contingency deployment.
- ***Why?***
  - Large investment in relevant simulation capability (examples include SDC, TACSSF, etc.)
  - Current capability is not being employed to provide current and evolving joint operational systems evaluation.
  - Multiple systems alternatives, PATRIOT improvements, THAAD, ERINT ARROW, GBR can be evaluated and architectures assessed for varying operational scenarios.
- ***Benefit:***
  - Provide early assessment and developer feedback of operational utility.
  - Assure development of doctrine tactics and procedures to match evolving operational capability.
  - Integrate theater defense simulation into test training, rehearsal with CINC battle staffs
  - Opportunity to use prototype systems for contingency operations.

Joint Theater Defense Demonstration



Requirements of the Experiment

Simulations exist for most system elements needed. They need to be made DIS-connectable and the real-time capabilities and needs of each must be assessed. Early experiments by industry and government indicate that it takes about six months and $4-5 million to complete a complex (DIS) simulation with validated results (DARPA estimates, IDA experiments) and the availability of Service operators motivated to help is ESSENTIAL. Ground truth (terrain, any historical data) and reasonably accurate simulations (matching the complexity of the D&protocol data stream--a missile must be complex and a satellite which passes only a few data signals doesn't) are needed. Preliminary simulations of new capabilities (Secure C4I links between systems, new sensors, interfaces with command authorities, etc.) can be made available fairly quickly for assessment in an operational context.

Desired Outcomes

The impact of new ideas for interoperability, finding and destroying incoming missile threats and assessing damage must be measured in realistic DIS scenarios with real operators using real sensor and intelligence data. Operators need to have the best data and conclusions available to allow rapid decisions in the battle context. Measured bounds on the best and worse sensor data, assessment predictions, timelines for prosecution will allow future planners to consider ideas like requesting data from AWACS and JSTARS and other aircraft in real time, directing attacks at launch points, etc. Given the power of DIS, operators will come up with methods, tactics and requirements of new data and capabilities that will greatly assist efforts to address Theater Missile Defense.

The Air Defense Mission includes force/headquarters elements from all the services deployed to the Theatre of Operations. The control of the air has been, because of technology and budget limitations, largely procedural and slow to adapt to the advancing Ballistic Missile threats. As a result of Desert Storm the psychological impact of the Tactical Ballistic Missile has been brought to sharp focus. The Department of Defense has pressed forward to develop THAADS, FEWS, Improved Patriot, SM-2 Block 4, ground based radar, and other systems to protect allied nations and combatants from this threat more effectively. Many, if not all of these new systems, have produced deliverable simulations for the purpose of evaluating service concepts, requirements and costs. In addition, many simulation facilities have been developed to assess advancing technology. These include the effort at SDC in Huntsville, AL, TACCSF at Kirtland AFB, NM, and the NTB at Falcon AFB, in Colorado. The DSB recommends that these facilities be connected to the ADS network and be wargamed with other Air Defense assets currently available to the CINCs and Services.

DEMONSTRATION #6: THEATER AIR AND MISSILE DEFENSE (CONT'D)

The Theatre Air Defense problem involves air, sea and land forces; the CINCS; the SDIO; and other elements of the development community. It is fortuitous that the timing of the ATBM System Component's development activity matches the readiness of ADS. The developer and the user are now able to examine alternative requirement sets, force employment, and development options as our operational capability evolves and matures. Furthermore, it leverages government owned simulators that are readily interfaced to the ADS.

In addition to the study of development and deployment options, these simulations can be employed to assist in training and readiness of the forces employing this capability.

THAADS = Theatre High Altitude Air Defense System (US ARMY)

FEWS = Follow-on Early Warning System (US AIRFORCE)

SM2 = Standard Missile 2 (US NAVY)

ATBM = Anti Tactical Ballistic Missile

ADS = Advanced Distributed Simulation

SDC = Strategic Defense Command

TACCSF = Theatre Air Command and Control Simulation Facility

NTB = National Test Bed

DEMONSTRATION #7: SUPPRESSING CRITICAL MOBILE TARGETS

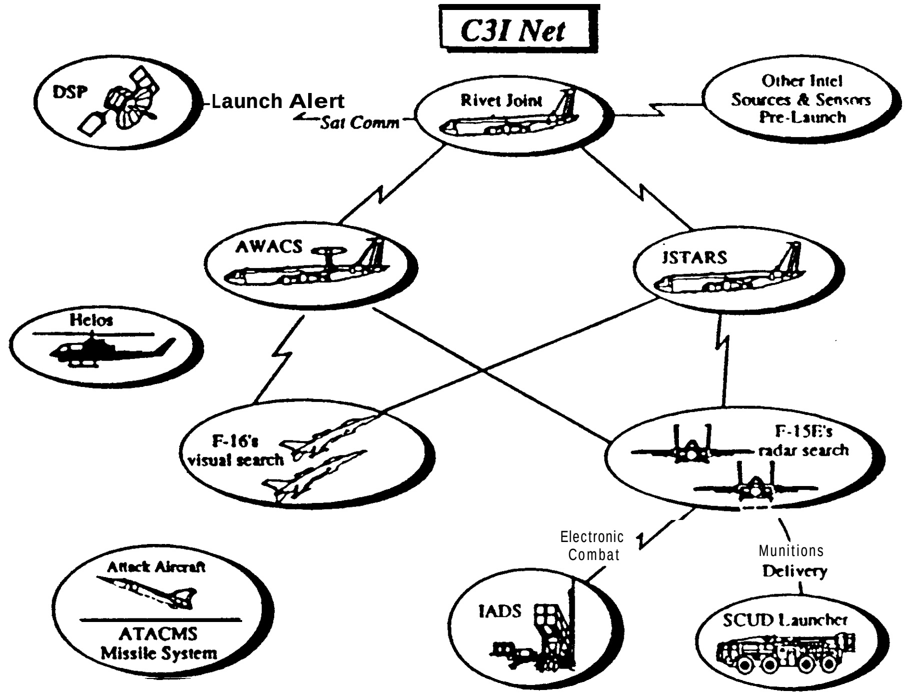
Elements of the Simulation: Since the kill train for the Critical Mobile Targets (CMTs) covers the gamut from initial intelligence community assessments through intelligence tasking and collection, to mission planning, tasking and execution by the Services, followed by feedback of battle damage to the intelligence groups. Simulations of current and proposed solutions to the CMT challenge should include elements from this entire process. Needed elements include: National Technical Means, with attention paid to making these products useful to theater combatants within the security guidelines; human interfaces and interconnects to the "stovepipes" for carrying intelligence data within the Services; mission planning; sensor systems (satellite, aircraft, ground based radar and unattended sensors); weapons and platforms, including air, ground, sea and autonomously launched devices; and opposing air, ground forces and sensor systems. Also included must be a range of terrain and threat scenarios, including many areas of the world where CMTs might appear.

Structure of the Experiment: A major element of the experiment involves finding the targets, planning an attack, and killing the targets, with damage assessment. Since timeliness is important, we need to look for new ways to interconnect intelligence data (National Technical Means, service strategic and tactical sources), theater sensors (JSTARS, ASARS, etc.) to decision makers (command posts, AWACS) in a more immediate manner, with displays and data base processing to show and exploit the value of these data. Another element is a strong capability for testability (ability to collect the right experimental data) and verification (operational realism, comparison to battle and OT&E results). A wide range of Concepts of Operation against CMTs should be addressed, including new players talking to new commanders. Trades between pre-launch strikes, tracking and hitting launchers, killing missiles in boost or glide phases need to be considered. Human decision times, times and methods for real-time mission replanning in flight or ground-based, time to find and track missiles and launchers, and times needed to put "metal on targets" must be measured, including using real operators in diverse DIS scenarios.

Requirements of the Experiment Simulations exist for most system elements needed. They need to be made DIS-connectable and the real-time capabilities and needs of each must be assessed. Early experiments by industry and government indicate that it takes about six months and $4-5 million to complete a complex (DIS) simulation with validated results (DARPA estimates, IDA experiments) and the availability of Service operators motivated to help is ESSENTIAL. Ground truth (terrain, any historical data) and reasonably accurate simulations (matching the complexity of the DIS-protocol data stream--an aircraft must be complex and a satellite which passes only a few data signals doesn't) are needed. Preliminary simulations of new capabilities (new wide-are sensors, imagery presentations to combatants, new data base and decision support computer presentations to planners, real-time replanning in the air, smart weapons, etc.) can be made available fairly quickly for assessment in an operational context.

Demo #7: PRECISION STRIKE (Critical Mobile Targets)

- ***Objective:***
  - Provide an end-to-end simulation architecture to support requirements definition, systems engineering trade-offs, and testing for precision strike scenarios.
- ***Why?***
  - Poor current capability to detect, locate and kill time sensitive critical mobile targets
- ***Benefits:***
  - Define requirements to achieve near-real-time sensor to shooter connectivity
  - Develop joint doctrine, tactics and procedures



DEMONSTRATION #7: SUPPRESSING CRITICAL MOBILE TARGETS (CONT'D)

Desired Outcomes

The impact of new ideas for interoperability, finding and prosecuting CMTs and assessing damage must be measured in realistic DIS scenarios with real operators using real sensor and intelligence data. Operators need to have the best data and conclusions available to allow rapid decisions in the battle context. Measured bounds on the best and worse sensor data, assessment predictions, time lines for prosecution will allow future planners to consider ideas like minimum response for assured kill, preemptive strikes, sensor retasking within threat activity time windows, etc. Given the power of DIS, operators will come up with methods, tactics and requirements of new data and capabilities that will greatly assist efforts to address Critical Mobile Targets.

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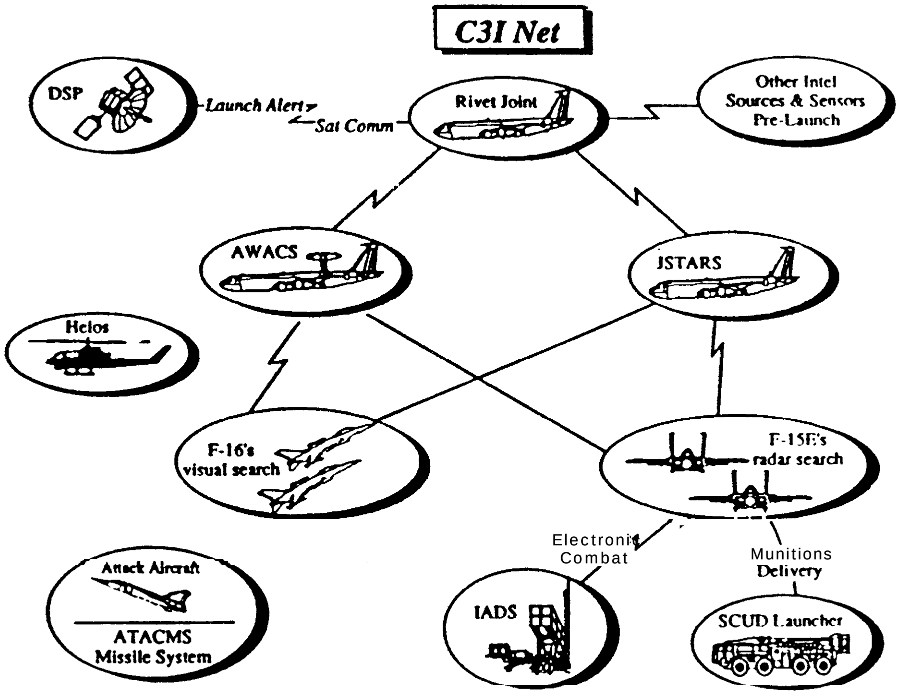

DEMONSTRATION #8: NETWORKED BATTLE GAMES

OBJECTIVE This demonstration aims at exploiting the expanding networks of commercial games that require multiple players. These fit the characteristics of ADS: person-in-the-loop, distributed simulation pitting one side against a skillful adversary.

WHY? To date, few of the commercial games are militarily relevant, that is, portray situations recognizable to military personnel as amenable to service or joint doctrine, tactics or techniques. Yet the services have developed commercially viable board games (such as "Firefight"); DARPA offers a $5,000 prize each month for computerized games; and the service academies have the capability to develop militarily useful games, own extensive computer networks, and have in their student bodies a large audience of user-surrogates for test and evaluation.

WHAT? The demonstration would catalyze, through IDA's Advanced Simulation Center, (1) development of candidate games; (2) examination of the latter's military worth, and (3) their "publication" as commercial software.

BENEFITS. The prospect is a WIN-WIN situation:

- Services are provided more channels for training and education.
- Commercial firms can profitably offer "realistic" gaming challenges to customers.

Demo #8: NETWORKED BATTLE GAMES

Objective:

- Assess the military value of collective, tactical games playable on low-cost computers networked via dial-up telephone lines, drawing upon:
  - Government-owned board games, such as *"Firefight".*
  - DARPA's monthly George Mason University prize contest for game inventors.
  - Original games developed at service schools.
- Establish test-beds at the Service Academies

Why?

- Rising generation is video-game, *"Nintendo tuned"* to computerized simulations.
- Telephone networking can serve reserve component training, recruiting, and skill-maintenance among detached combat arms personnel.

Benefit:

- Effective outreach from military services with little or no impact on DOD budget.

DEMONSTRATION #9: BATTLEFIELD VISIBILITY

OBJECTIVE. This demonstration would exploit ongoing and projected training of armed services' exercises in the SW USA both for the purposes of assessing visual systems that could both enhance actual operational effectiveness, and facilitate introduction of ADS. While deployed and anticipated electronic visual systems for aircraft are well advanced, those for AFV are comparatively primitive. Hence, we should seek to augment the latter, and to use electronic visual systems to channel information from both the real world and the synthetic battle environment to participants in the exercises.

WHY? AFV vision aids (aside from the commander's binoculars) are limited to vision blocks, and mono-directional visual aids (e.g., driver's view-screen, weapon sights). Since safety or IFF often depends on visual recognition, improvements are warranted. Moveover, situational awareness could be enhanced by (1) broadening the field of view of the driver and the loader,and (2) elevating the perspective of the AFV commander. To the degree that vision aids are electronic in either AFV or aircraft they are amenable to inputs from virtual or constructive simulations.

WHAT? The demonstration would assay two technological advances: (1) to enrich visual inputs to tank crews by strap-on TV cameras and screens, and by a turret bustle-rack module mounting an extensible mast topped by the sight from the Scout Helicopter, and external clamp-on ClGs to inject icons from other simulations into the turret's sights; (2) further, the demonstration would experiment with means to inject iconographic data from constructive or virtual simulations into existing or oncoming visual displays on aircraft.

BENEFIT. The pay off is for both war and peace.

- Warriors that can see better and further to fight better.
- Warriors trained against realistic threat environments enabled by ADS to perform better.

Demo #9: BATTLEFIELD VISIBILITY

OBJECTIVE:

- **Real world:**

  Experiment with strap on vision devices for armored fighting vehicles (AFV) to enhance situational awareness. E.g. 1) the mast mounted sight from Scout helicopter to elevate the view of the tank platoon leader, 2) rear or side view TV for Bradley "dismounts," M-l tank driver and loader. (N.B., Aircraft visibility enhancers, e.g. LANTIRN, NIGHTHAWK or MAVERICK are ahead of the sensors available to AFVs.)

- **Simulation:**

  Use the electronic vision devices on real vehicles as part of simulation exercises. Because advanced vision systems are electronic we can inject icons from virtual or constructive simulations into exercises with actual equipment. DIS-compatable wireless interfaces are needed.

WHY?

- In armored fighting vehicles, height above ground is a prinicipal factor in probability of detection, and 360^{o} observation is important for security and safety.
- Promotes interaction among all three forms of simulation, since "seamless simulation" could proceed from DIS inputs to an operational visual display.

BENEFIT:

- Earlier, more assured threat detection and advantaged target engagements
- More realistic ADS battle environments

DEMONSTRATION #10: INTEGRATED TEST AND TRAINING RANGES, FACILITIES, AND ACTIVITIES

The Department of Defense (DOD) has invested billions of dollars in developing training and test ranges in the southwestern United States. The ranges are under the control of the Army, Navy, Marines or Air Force. Each with its own mission, projects, **and** workload. Interoperation is limited to only a few centers.

The Chairman of the Joint Chiefs of Staff (CJCS) has recommended that the Defense Science Board (DSB) attempt to quantify the potential for modeling and simulation (M&S) to improve Defense acquisition, military training, and joint operations through the use of training and test range interconnectivity and virtual reality modeling methodologies. The SWUSTTRC provides an area to meet the CJCS' request. The instrumented ranges in the SWUSTTRC will exploit the convergence of three types of tactical engagement simulation: virtual, constructive, and live range exercises.

Proposed exercises in SWUSTTRC might focus on: a special operations exercise at the National Training Center (NTC); actual use of systems such as Joint Direct Attack Missile (JDAM) and Tomahawk Land Attack Missile (TLAM) for deep precision strike; virtual employment of JDAM, TLAM, and other systems; Third Fleet exercise (off the Coast of California) with a T&E operation; electronic warfare exercise at China Lake; UAVs with various sensors; a forced entry exercise at Camp Pendleton; all supported by actual and virtual aircraft from such places as Fallon, Nellis, Miramar, and possibly aircraft carriers. This is strictly an example to communicate intent. The user communities would design such an exercise to meet their needs.

The DSB makes the recommendation for an exercise in the SWUSTTRC to leverage the country's continuing investment in its test and training ranges. Networking these ranges together and adding both constructive and virtual simulation will improve joint readiness; concept development; and weapons simulation and test validity. Further, the experiment will create an environment for regular CINC evaluation, understanding, and integration of emerging capabilities.

Leveraging these investments for early and continual involvement of user communities in systems development from concept through deployment will vastly improve the acquisition process. A combination of such exercises with simulation will create opportunities for realistic joint training at the Joint Task Force level, exercising contingency capabilities, and introducing new capabilities into contingency planning.

With the increased emphasis for joint operations, more efficient employment of the existing ranges is required.

Demo #10: INTEGRATED TEST AND TRAINING RANGES, FACILITIES AND ACTIVITIES

- ***Objective:***
  - To provide integrated joint and service testing and training capability by:
    - Networking, real, virtual and constructive prototypes with range exercises.
    - Better exploiting existing training and testing ranges, facilities and activities.
    - Early development of doctrine, tactics and contingency capability by regularly training operators using live, virtual and constructive prototypes .
    - Use test results interactive with simulation.
- ***Why?***
  - Leveraging the continuing investment in ranges, test facilities and laboratory simulations will improve readiness, concept development, and weapons and test validity.
  - Create an environment for regular CINC evaluation, understanding and integration of emerging capabilities.
  - Create more focused efficient testing.
- ***Benefit:***
  - Leverage the investment.
  - Early and continuing involvement of the user from concept through testing.
  - Better introduction of new capabilities into contingency plans.
  - Provide consistency and correlation among simulations, testing and training

DEMONSTRATION #10: INTEGRATED TEST AND TRAINING RANGES, FACILITIES, AND ACTIVITIES (CONT'D)

A key element in connecting these various centers is a network which builds upon existing connectivities such as the Air Force (DATS) adding programmed (and funded) connectiveness such as T&E Range Internetting System (TERIS) and Defense Simulation Internet (DIS), with additional connectivities not yet identified to establish a complete network for interoperability for test and training evolutions such a powerful tool provides easy acces to the numerous elements which should participate in life cycle decisions as well as significantly improve force readiness through greater combat realism.

Demo #10: INTEGRATED TEST AND TRAINING RANGES, FACILITIES AND ACTIVITIES

- ***Objective:***
  - To provide integrated joint and service testing and training capability by:
    - Networking, real, virtual and constructive prototypes with range exercises.
    - Better exploiting existing training and testing ranges, facilities and activities.
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- ***Why?***
  - Leveraging the continuing investment in ranges, test facilities and laboratory simulations will improve readiness, concept development, and weapons and test validity.
  - Create an environment for regular CINC evaluation, understanding and integration of emerging capabilities.
  - Create more focused efficient testing.
- ***Benefit:***
  - Leverage the investment.
  - Early and continuing involvement of the user from concept through testing.
  - Better introduction of new capabilities into contingency plans.
  - Provide consistency and correlation among simulations, testing and training

DEMONSTRATION #11: REALISTIC ELECTRONIC COMBAT TESTING AND TRAINING

The electronic combat (EC) simulation demonstration is to provide realistic electronic warfare training, and a means to evaluate EC requirements. The demonstration exploits the fact that current and future EC systems communicate to operational data displays using a weapon system data bus.

DEMONSTRATION: This demonstration selects a ground-based desktop system capable of communicating with a weapon platform's defensive avionics data bus. The desktop system interactively exercises the EC system display or equipment by inserting data through the platform data bus. The demonstration requires: 1) development of software to permit the weapon system and desktop to intercommunicate, and 2) the desktop threat scenario software. (The demonstration starts with the radar wanning aspect of EC, but does **not** limit EC similation to just situational awareness.)

IMPORTANCE: Current land-based simulators for EC weapon defense systems are expensive, marginally mobile, and far too few in number. Additionally, in live rehearsal there exists the possibility of compromising operational security by geo-location or radiation of target-unique signals.

Using the desktop, scenarios can rapidly be reconfigured to reflect the current world configuration e.g., systems used by friendly coalition forces and friendly systems used by enemy forces, such as Mirage aircraft used by Iraq in Operation Desert Storm.

Insertion of data into the platform data bus can provide a synthetic environment in a form both developers and users can evaluate the system and its proposed modifications. From concept to production, the user can simulate a change in either EC environment or equipment, and see the effects of the change. Captured data can be analyzed and used in the decision process. (Off-board manipulation of the platform data bus has the potential to be migrated next to maintenance malfunctions.)

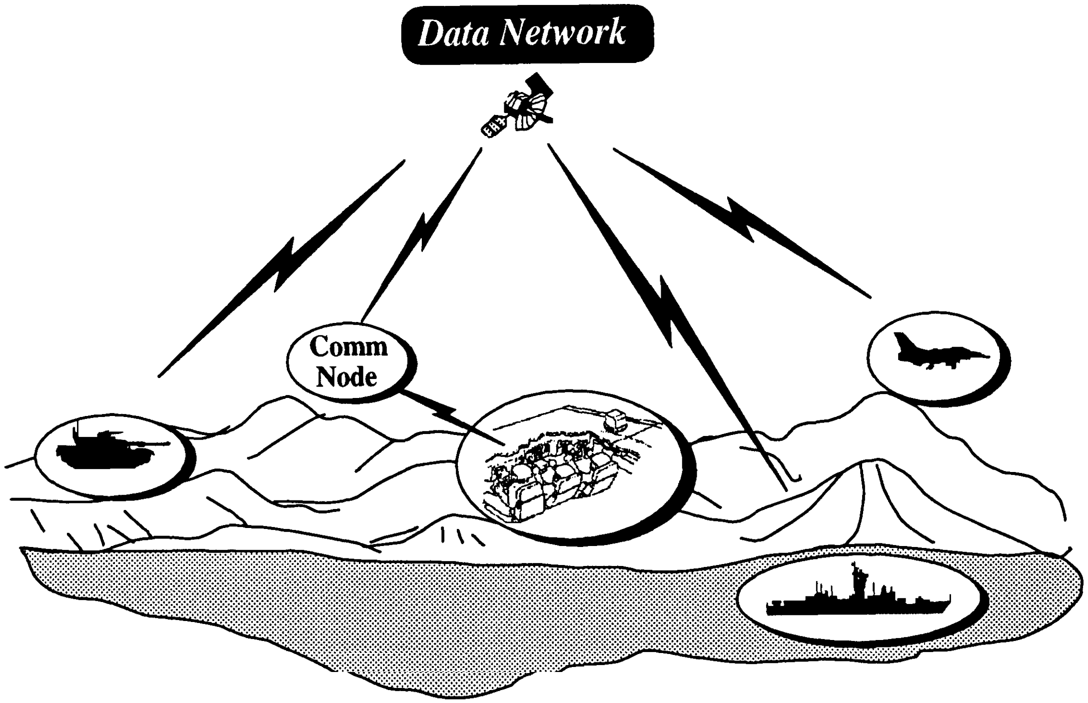
EXPECTED OUTCOME: Training and readiness will increase due to realistic EC training without compromise of security. Early and continued user involvement in the acquisition process provides a contractor-developer-user feedback cycle which should result in higher quality requirements for development items introduced early into the training process.

Demo #11. ELECTRONIC COMBAT SIMULATION

- ***Objective:***
  - Using ground based microsystem technology, provide secure interactive exercise of electronic combat systems. Accomplish this by direct insertion of data.

- ***Why?***
  - Current land-based simulators are expensive, marginally mobile, and too few in number.

- ***Benefits:***
  - Realistic electronic combat training.
  - Rapidly reconfigurable scenarios without compromising security.
  - Synthetic hardware emulation and requirement analyses with early and continuing user involvement.



DEMONSTRATION #12: IMPROVING WARFIGHTER C4I INTERFACE

OBJECTIVE. The objective of this demonstration is to provide a simulation architecture that introduces theater intelligence support into regular operational training exercises and development and operational testing. Requirement definition, system engineering trade offs, technology development and prototype testing will be supported by the effort. Real and constructive inputs from Guard Rail and AWACS; JSTARS Simulator; real, constructive and virtual input from national systems such as U2 and overhead satellite will be integrated into the simulation architecture. AWACS will be given an onboard capability to add constructive and virtual opposition forces to real forces and display variable size raids on Blue Air and ground forces displays.

WHY? Currently there is no regular support from Command, Control, Communication, Computers, and Intelligence (C4I) assets infrequent training, testing, and assessment. The imperative is to train operational customers and intelligence suppliers. Users now see surveillance output from the C4I assets in scripted distillations. They need experience in sorting and analyzing data from varied sources of varied validity.

WHAT? The demonstration will develop an architecture and process for providing C4I input into the training, testing assessment process. The testbed will include command and control systems, C4I assets or their simulation.

BENEFITS. The benefits of the demonstration include:

a. Ability to better integrate C4I assets into contingency planning and execution.

b. An enhanced user driven requirements process and an equipment development techniques.

c. More focused intelligence suppliers.

d. Better educated operational customers.

Demo #12: OPERATOR AND SUPPLIER C4I TRAINING

- ***Objective:***

  Introduce intelligence support into regular operational training exercises and testing with:

  - Guard Rail real and constructive inputs; JSTARS simulator; AWACS real and constructive inputs; real, constructive and virtual national systems (overhead, U2, etc.) inputs.

  - Give AWACS an onboard capability to add constructive and virtual opposition forces to real forces and display variable size raids.

- ***Why?***

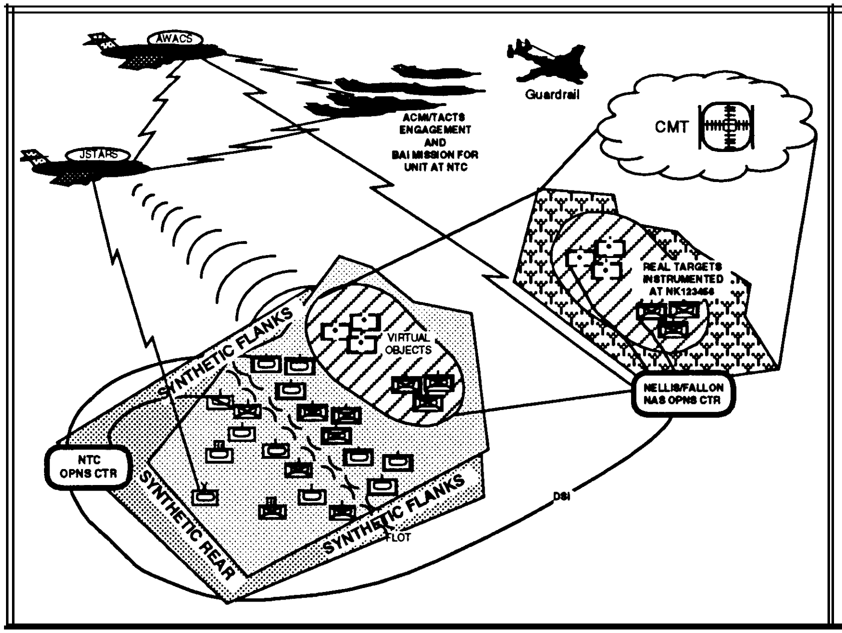
  - Currently no regular peacetime support from C4I assets in frequent training, testing, and assessment. Need to train operational customers and intelligence suppliers.

  - Users now see surveillance output in scripted distillations. Need experience in sorting data from varied sources of varied validity.

- ***Benefit:***

  - Ability to better integrate C4I assets into contingency planning and execution.

  - Educated operational customers. Focused intelligence suppliers. User driven requirements



APPENDIX C:

LONG RANGE SENSING AND ATTACK

Report of
Long Range Sensing: and Attack Panel
of
Defense Science Board 1992 Summer Study
on
Simulation, Readiness and Prototyping

Introduction

The questions addressed by this Panel on Long Range Sensing and Attack systems were:

1. How should these systems impact exercising[1] of the general forces?

2. How should the operators of these systems be trained?

3. Should these systems be used to supplement the instrumentation of the ranges, for example, to expand the exercise operations to theater scale?

The Long Range Sensing and Attack systems were taken to include the following typical examples:

JSTARS	Manned weapons
AWACS	F-15, F/A-18, AV-8
GRCS	Unmanned weapons
ASARS	TLAM, ALCM
NTM	ATACMS, TSSAM/BAT

These systems and questions are relevant to the work of the Task Force for three primary reasons:

- These sensors observe a wide area, potentially including both friendly and enemy forces. Thus the data provided can impact all areas and levels of combat.

- Because the coverage transcends all force elements, these sensors can provide an important base for interfacing joint or coalition forces.

- With a detailed view of large areas, these sensors offer the potential for augmenting range instrumentation and providing ground truth.

Aside from AWACS, the long-range sensing systems are generally Theater or National assets and are largely unfamiliar to the operating forces. JSTARS is new with only limited exposure to operators. The rest have historically been isolated from the operators by their association with intelligence. As a result of this lack of exposure to the sensors, the ability of the operational forces to utilize the capabilities has been limited. The development of effective processes, procedures and systems integrating these capabilities into war fighting can only occur through the understandings which come with extensive use by the forces.

Long-range surveillance and battle management platforms will have a profound impact on macro-scale tactics in the future. Consequently, large (eg: JTF-level) exercises or simulations must include these assets, to train commanders in their impact on situation assessment and targeting. The tendancy in the future will be to provide the sensor data to lower and lower levels for targeting, hence these systems will probably need to be represented in exercises at brigade and lower levels. The nature of the data representation (eg: target type and coordinates, group tracks, raw detections/imagery) required at each level is not well understood today and is closely tied to evolving operational concepts.

[1] "Exercising" used to include training, system assessments, and testing/ evaluation.

Sensor Representation for Training and Testing

There is no question about the need for regular, realistic and comprehensive availability of the long-range (Theater and National) sensor data at all levels of the forces for training and testing purposes. On the other hand, these sensors are all limited resources with many demands for observation time. In addition, each sensor/platform typically costs hundreds of millions of dollars so replication is not a reasonable solution.

This raises the question of the adequacy of synthetic data for representing the long-range sensors in exercises. For the moment, assume that one can capture the position, motion and status (aspect, emissions, etc) of all elements involved in actual field operations. The equivalent "ground truth" knowledge about the synthetic forces (either virtual or constructive) is straightforward since the information is generated within a cooperative computer. Three classes of long-range sensors should be considered:

(1) moving target radar (eg: JSTARS)

(2) SIGINT (eg: GCRS)

(3) imaging systems (eg: ASARS, EO/IR)

Given the assumption of good ground truth, synthetic moving target radar and SIGINT data streams at either the raw- or interpreted-data level, can readily be generated and quite realistic. Data users should be unable to discern whether real sensors or simulations are providing the data stream. The same is true for imagery data at the interpreted-level (ie: icon representations of an interpreter's conclusions).

Completely synthetic imagery at the raw data level (ie: a photo or an image), on the other hand, depending on resolution, is generally not a practical way to proceed. However, manipulation of an imagery data base and insertion of synthetic targets appears reasonable. For example, for a specific exercise area, eg: Nellis AFB, a data base of aerial photography could be used with a target array (eg: enemy air defense battery) inserted to achieve realistic representation of the data from a long-range sensor. If, in an exercise, there is to be a real attack on a surrogate enemy air defense system, the true signature of the surrogate would be that inserted. The only cases where raw-data level should be required are those involving engagements directly involving visual contact with a target.

Areas of the "theater" outside the region of actual field operations, can be realistically represented by simulations to extend the exercise area, based on the situation assumed to exist there. Thus, long-range sensing and attack can be synthetically brought to the battle. The exceptions to this generality are some cases of terminal engagement using imagery and man-in-the-loop attack against synthetic target arrays where, as discussed above, real target surrogates in the field must be represented in the synthetic data. The following table summarizes the sensors and the relevant approaches.

Simulation Approaches	Moving Target Radar	SIGINT	Imagery
	Sensor Classes		
Synthetic data streams faithful to real field situation	√	√	Raw data not practical. Icon is practical.
Data base of background imagery with implanted target images for real field operations	Not reqd	Not reqd	√
Extensions of "theater" beyond area of actual field operations	√ But need data base	√	√

Table I
Simulation Approaches to Sensor Classes

In each case, a "√" indicates the user inability to distinguish real and synthetic data from long range sensors. In all of this, it is important to assure consideration of details such as delay and latency, performance (eg: Pk, Pd, TLE) based on physical measurements, masking/intervisibility, and EW effects. Sensor errors and noise can and must also be represented.

Synthetic data thus can adequately provide participation of long-range sensing and attack but depends on faithful representation of priorities and delays in sensor tasking and management. Occasionally, the actual sensors should be included in exercises to assure that the synthetic version is not diverging from the realistic, and to provide appropriate data bases.

An example of a data base requirement for moving target radars is the representation of JSTARS looking in the area of a "virtual division". The question is what detailed motion occurs in a typical division in bivouac, garrison or on the move. The use of the JSTARS sensor itself, observing a divisional area, is probably the most practical way to determine what typical motion occurs. Without this understanding, at least in a general sense, any synthetic view is not likely to be realistic. For example, an important enemy target is a command post and that probably can be distinguished by the vehicle and helicopter motion into and out of the command post. Having a realistic representation of typical CP motion is critical to training operational exploitation of it.

Exercising the Forces and Sensor Overators

Long range sensors will play increasingly critical roles in the progress of future battles and operator interpretation of sensor products is probably the least understood but most critical link in the chain utilizing sensor data. Operator performance under stressing conditions is the key to utilization of the sensors and operational evaluation of sensor effectiveness. It follows that sensor interpreters should be "in the loop" in large scale simulation exercises.

This should not be taken to imply that sensor interpreters should not be trained off-line, they should. Developing photo interpreters using real photographs and developing MTI radar operators using real or recorded data is essential and should be divorced from major exercises. However, it is equally important that the operators participate in exercises. The analogy to training and exercising tank gunners is appropriate; a gunner uses UCOFT to develop skills, field firing to test these against real equipment and then SIMNET to practice these skills and associated teamwork in a complex environment. The exercises are similarly critical to the sensor operators whose greatest challenge will be finding time-sensitive targets under realistic battlefield conditions.

The forces themselves need considerable experience both with the sensor data in relatively raw form in some cases (eg: JSTARS MTI) and with the operator/interpreters at all echelons involved. The operator skills and performance and the rapidity of interpretation and dissemination will impact the force performance more than that of almost any other individual involved. The experience with the sensors and the operators is essential for the commanders to understand what the sensors can do for them, to learn how to integrate them with operations, to develop operational concepts, and to appropriately develop secondary dissemination procedures. This experience can be provided completely adequately through the use of simulated sensors and synthetic data.

Realistic real-time image generation with correct representations of tactical targets should be a goal and is achievable with current technology. This was described briefly above and involves taking recorded images of the tactical areas (either operational such as Iraq or exercsie such as NTC) and embedding synthetic targets into the images. Synthetic target data can be acquired from turntable measurements of real or surrogate targets or, in some cases, physically accurate scale models of targets (eg: Mattel models).

Images generated in this manner should provide for an exercise scenario such as the following: A long range sensor (of any kind) determines that there is a critical mobile target at a specific spot 80 km into "hostile" territory. That target will move down the road and stop at some point known only to the exercise coordinators. They will provide a synthetic image for that circumstance as though it were taken from a long focal length telescope and will provide that image to the operators. The quality of the representation must be adequate for a real F- 15E pilot, if he is provided with the image while in the air, to use it to find and attack the target. It is this visual (or IR sensor such as LANTIRN) involvement which requires the high fidelity synthetic image.

The Synthetic/Real Mix in Exercises

A word of caution about the degree of exercise use of simulated sensors in general, is in order lest the reader assume that we believe that simulation alone can provide what the operational forces need for exercises. There are important factors which dictate that real sensors be used in the exercises occasionally. Depending on the objectives of the exercises, this might mean once per quarter, once per month, or once per week but the need for real sensor participation surely is a small fraction of the total exercise time.

The important considerations include the following:

- Very early in the use of simulators for long range sensors, the real sensors should participate and should be widely visible to the users, almost ostentatiously. If the sensor data obviously comes from real sensors, the users will trust it to be realistic (although, in fact it may be less so than synthetic!) and the use of synthetic data in this application demands a cultural shift. The simulated sensors can then be substituted and should be tranparent to the users.

- As mentioned above, there is a need to provide data bases that are realistic as a basis for the synthetic data streams. An example is the need to understand the motion inherent in a large force either deployed to a forward area and in defense or attack; this understanding would then be used to define the typical motion of JSTARS data in areas outside the actual field exercise region.

- Real sensors and sensor data streams will introduce some different problems and some sources of errors that the synthetic designers will not have thought of and thus occasional participation of the real sensors will provide "realism checks" and validation of the synthetic data approaches.

- Interoperability of sensors, ground stations and associated communications are critical and often not done well. To some degree, these can be simulated but usually are not adequate. Therefore, the use of real sensors is necessary to provide continuing interoperability verification.

What Do Simulators for Lonn Range Sensing Look Like ?

The above discussion could lead readers to visualize very large and complex simulators with large scale computational requirements. Such is not the case.

A very cost effective sensor simulator could reside solely within a high performance commercial workstation. The simulation or ground truth, derived from simulation truth for virtual forces and from instrumentation for real units, would be provided through a LAN or its equivalent. The simulator workstation would have disk-resident target and terrain models corresponding to the exercise region; these would be developed beforehand. The simulated sensor displays could be generated in this same workstation operating in background mode while the foreground task emulates the normal operator interface to the sensor interpreter. In the case of local exploitation, the products could also be used locally or exported via LAN to any available and appropriate C3 links. Alternatively, the sensor data streams could be provided to the appropriate tactical systems belonging to the forces.

It should be apparent that the creation of simulators for the long range sensors is not a major development. Relatively straightforward software for a workstation based simulation, should be completely adequate. The major effort required is to provide the ground or simulation truth. For virtual forces this is available directly from the force simulations themselves. In the case of actual forces in the field, it requires access to the same instrumentation that is required for the exercises.

Potential for Long-Range Sensing Svstems to Augment Instrumentation

The engagement of forces in exercises, particularly when they may be in physically separated locations, requires a detailed understanding of the position/motion of each element. Various systems have been built to provide these data (eg: MILES, ACMI) but these were not built to interoperate among themselves or with synthetic force representations. In order to interface synthetic and multiple real exercises, the "common grid" must be provided to assure that all can be expressed in a single set of coordinates. There are at least three approaches which can be considered:

- Modify existing range systems and provide "translators" to interface them.

- Create a new system, probably GPS based.

- Use the capabilities of long-range sensing systems to locate all elements in real time.

The first is being examined by several groups, may be practical as a short term solution but is likely to be limited in flexibility for the longer term.

The use of GPS receivers on each element plus a short range transmitter to report postion, motion, and status is straightforward, probably low cost, and limited only by the line of sight communications links required to collect the data. Any given exercise area is on the order of a few n-riles across so a small number of elevated communication relay stations generally could avoid terrain masking and assure access. For example, one or a few tethered balloons (a la "Seek Skyhook") for relay to a central computing terminal could assure direct line of sight to all the terrain of interest. These balloons have been demonstrated with long endurance. For particular situations, towers, mountaintops, a UAV or even a satellite might be prefered. In any case, the feasibility is not an issue.

The question then is, can the long-range sensors offer a better solution or supplement one of the other approaches. Consider the following:

- It is possible to place transponders on all elements. These could be designed to respond only to coded JSTARS or AWACS transmissions. The airborne radar could then distinguish specific units on the ground, potentially useful in battlefield IFF as well as in range instrumentation. It should be noted that a GPS-based reporting transmitter has similar IFF potential.

- The accuracy of element location is limited by the radar target location error (TLE).

- The approach works only for the elements which are directly in line of sight to the radar and the radar, in wide area coverage modes, typically would observe at low depression angles, exacerbating the masking.

- The utility is obviously dependent on the availability of a flying JSTARS or AWACS in the exercise vicinity.

It would appear to be unduly limiting to make the exercises dependent of the availability of one of these expensive and limited systems so it is essential that the element location problem be solved by other means. Once solved, then the question becomes the added utility of the long range sensor for range purposes.

It might be that use of a long-range sensor for this purpose would be less costly for occasional use involving an exercise area that is only rarely used. This cost comparison should be with the temporary provision of a GPS based approach. Intuition suggests that the latter would be the preferred solution but an analysis should be undertaken.

Conclusions

The use of synthetic data representing the long range sensing and attack systems is generally practical and acceptable. It should be adequate to pass the criterion of being indistinguishable from the use of the real system to most participants.

The dependence on synthetic data must be backed up by frequent use of the real systems, both in exercises and in data collection to support realism of the synthetic representations.

The dependence on long-range sensing systems to provide element location data on the exercise ranges is not a good approach. A simpler, more straight-forward location and status system based on GPS is preferred.