Distributed Interactive Simulation of Combat

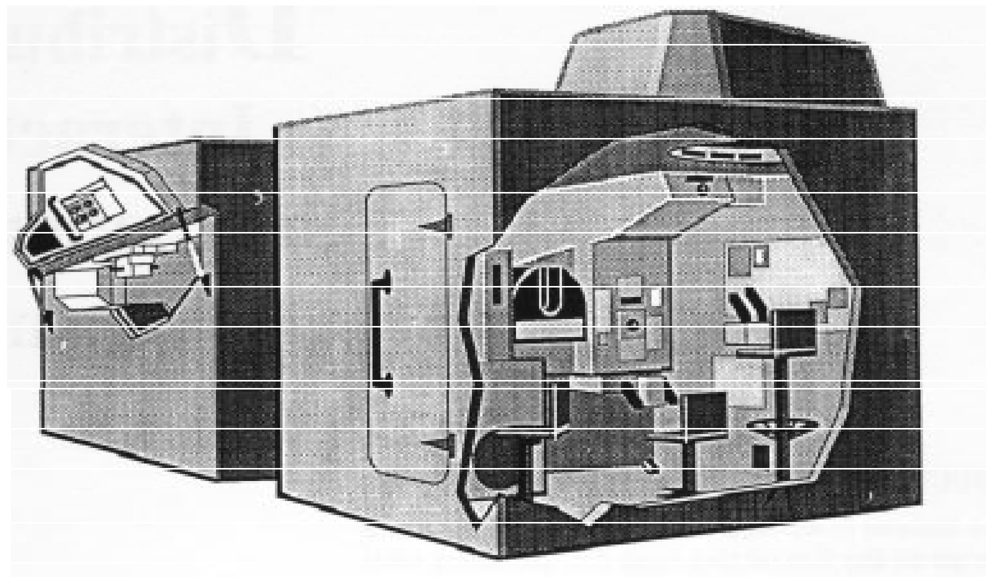
INTRODUCTION: PREPARING FOR THE NEXT WAR

> [The Romans] do not begin to use their weapons first in time of war, nor do they then put their hands first into motion, while they avoided so to do in times of peace; but as if their weapons did always cling to them, they have never any truce from warlike exercises; . . . nor would he be mistaken that should call those their exercises unbloody battles, and their battles bloody exercises.—Flavius Josephus, *De Bello Judaico* [*The Jewish War*] (79)

The military is proverbially accused of always training for the last war. To avoid this predicament, the U.S. military makes extensive use of simulators, simulations, and exercises, designed to emulate present or projected conditions. Models and simulations are used for several important purposes: training (to maintain readiness), analysis (of the effects of proposed tactics or system acquisitions), planning and rehearsal of operations, and demonstration of new technologies. Simulators, such as the Link Trainer, have been used primarily for training and mission rehearsal. More abstract simulations and models have been used for analysis and operations planning.

The simulation entry on the Critical Technologies List issued by the Director of Defense Research and Engineering (DDR&E) always stood as an area of undisputed superiority over the former Soviet Union. In today's changed world, modeling and simulation technology is one of 20 ''technology areas'' selected by the Department of Defense (DoD) for research and development funding emphasis. DoD's Defense Modeling and Simulation Office (DMSO), founded in 1991, has the lead in structuring DoD's approach to modeling and simulation, especially the high-tech forms.

FIGURE 1: SIMNET M1 Tank Simulator



SOURCE: Perceptronics, Inc., 1995.

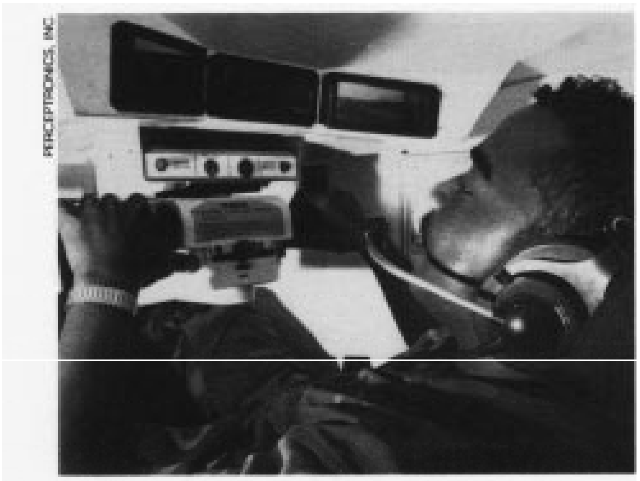
Advances in the technologies of microelectronics, computer networking, and computer graphics have led to supercomputers, the Internet, and synthetic environments for virtual reality (VR). They have also made possible a new kind of military training, pioneered by the Defense Advanced Research Projects Agency (DARPA—now ARPA[1]) in its Simulation Network (SIMNET) program, which began in 1983.

SIMNET began as a Tank Team Gunnery Trainer to replace existing tank simulators. Through adroit use of increasingly capable and economical computer equipment, SIMNET's developers expanded their system from a tank simulator to a tank battle simulator for company-sized units. Multiple interconnected tank trainers maneuvered on the same imaginary battlefield and cooperated to engage a common enemy. Their crews sat inside tanklike boxes (see figure 1) and viewed the imaginary battlefield through television screens mounted where the vision ports would normally be.

DARPA's SIMNET program ended in 1989, but the simulators, communications protocols, and network developed by the program are still being used and upgraded by ARPA's Advanced Distributed Simulation (ADS) program, the Army's Battlefield Distributed Simulation-Developmental (BDS-D) program, and other Department of Defense (DoD) programs (see box 1). The *name* SIMNET still occurs in the "SIMNET/ Close Combat Tactical Trainer" line item in the DoD Comptroller's 1995 *Procurement Programs* (P-1) report to Congress (189). The term is still applied to simulators, networks, and simulations that still use the SIMNET communications protocols, which have been superseded by the Distributed Interactive Simulation (DIS) protocols.

A distributed interactive simulation is "distributed" in the sense that simulator computers at

[1]The Advanced Research Projects Agency was established in 1958, renamed the Defense Advanced Research Projects Agency in 1972, and renamed the Advanced Research Projects Agency in 1993.



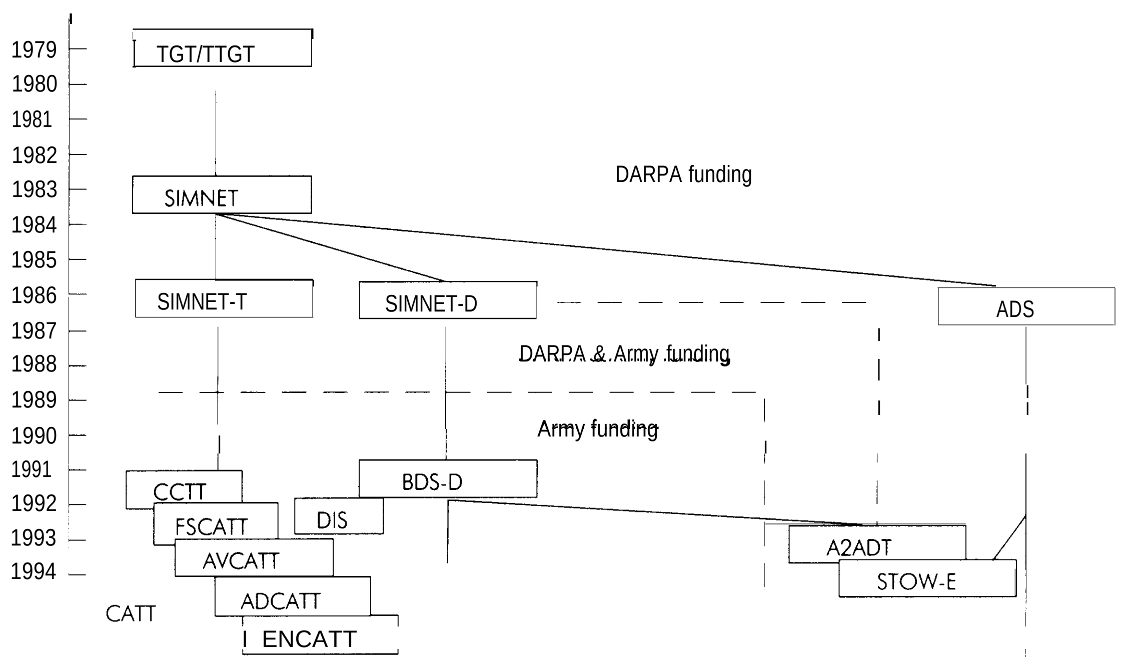
Driver's compartment of a SIMNET M1 tank simulator. The driver stem the tank with handlebars and throttles it by rotating one of the handgrips, much like driving a motorcycle, while viewing the virtual world outside through three vision blocks-displays of computer-generated imagery where periscopes would be on a real MI. When he drives overstimulated rough terrain, electromechanical actuators move his seat so that he feels bumps. The driver communicates with other crew members over an intercom system and hears simulated engine noise, firing of the tank's gun, and other sounds of combat.

Crew compartment of a SIMNET M1 tank simulator. The loader's position is closest to the camera, the gunner's position beyond and to the left, the commander stool beyond and to the right. The loader has one vision block; the gunner has one that shows finer detail, and the commander has several vision blocks, but cannot open the hatch for an outside view.

multiple training sites nationwide are connected by means of a local-area network (LAN; see figure 2), which in turn maybe connected to a wide-area network (WAN) such as the the Defense Simulation Internet (DSI) (see figure 3). Trainees can enter disparate tank, helicopter, or other simulators and all participate in the same simulated combat. The simulation is "interactive" in the sense that humans interact with the computers to influence the simulation. The battle does not follow a set script, and trainees win or lose on the basis of their performance. The trainees fight a similarly networked opposing force, which may be a combination of *virtual* forces-real people operating simulators-and semiautomated forces (SAF)--vehicles and weapons simulated by computers with humans providing operational supervision. In both the virtual forces and the semiautomated forces, human behavior is simulated by humans, albeit humans not affectedly the many stresses of real combat.

These simulations hold promise beyond their capability to train equipment operators to work as a team, Ever larger numbers of networked tanks, airplanes, and other platforms allow higher echelon commanders to plan operations and conduct them in simulation before conducting them in combat. Proposed weapon systems can also be simulated in order to evaluate and, if necessary,

BOX 1: SIMNET's Geneolog



KEY:

A2ATD: Anti-Armor Advanced Technology Demonstration
ADCATT: Air Defense Combined Arms Tactical Trainer
ADS: Advanced Distributed Simulation
AVCATT: Aviation Combined Arms Tactical Trainer
ARPA: Advanced Research Projects Agency
BDS-D: Battlefield Distributed Simulation-Developmental
CATT: Combined Arms Tactical Trainer
CCTT: Close Combat Tactical Trainer
DARPA: Defense Advanced Research Projects Agency
DIS: Distributed Interactive Simulation [Project]
ENCATT: Engineering Combined Arms Tactical Trainer
FSCATT: Combined Arms Tactical Trainer
STOW-E: Synthetic Theater of War—Europe
TGT: Tank Gunnery Trainer
TTGT: Tank Team Gunnery Trainer

redesign them—before the first unit is built. This technique is known as *virtual prototyping.*[2,3]

Creating a shared virtual battlefield requires more than computers and display equipment. It requires collection of detailed weapon, terrain, and climatic data. Some simulators can use data collected and archived for other purposes, including platform navigation and weapon guidance, opening up many possibilities to improve all applications of modeling and simulation and to tie them more directly to actual combat.

High-tech simulation has critics as well as boosters. Some critics have seized on the possibility of "negative learning": trainees who have re-

[2]ARPA's Simulation-Based Design (SBD) (157,158,159, 160) and TransTech (161) programs and the Army's current Louisiana Maneuvers (LAM) program (138, 199) are using virtual prototyping of proposed military equipment to reduce acquisition cost and time and to increase operability and supportability.

[3]There are many nondefense applications of virtual prototyping. Well-known examples include Boeing Aircraft Company's virtual prototyping of its new 777 commercial transport aircraft, and NASA's use of Lockheed's Preview (for "Prevent Real Errors by Virtual Investigation of Engineering Worlds" (5)) software to visualize the first Hubble Space Telescope servicing mission, which identified a need to redesign the Corrective Optics Space Telescope Axial Replacement (Costar) (35,5 1,86, 137).

BOX 1: SIMNET's Gene

DARPA's SIMNET project began in 1983 to exploit technologies and concepts developed in DARPA's Tank Gunnery Trainer project.[1] The Army became a cosponsor in 1985 and began using the technology for training (SIMNET-T) and research and development (SIMNET-D). Meanwhile, DARPA founded the Advanced Distributed Simulation program to continue technology development on its own. In 1989 DARPA stopped funding the SIMNET-T and SIMNET-D projects, which two years later became the Army's Combined Arms Tactical Trainer (CATT) project and Battlefield Distributed Simulation-Developmental project, respectively. The CATT project is a collection of several projects to develop interoperable distributed simulation equipment for several combat arms. Its Close Combat Tactical Trainer project, for training armored units, most closely resembles the early SIMNET project; other CATT projects are for training fire support, aviation, air defense, and engineering units. DARPA—now called ARPA—jointly fund the Anti-Armor Advanced Technology Demonstration program. ARPA's Advanced Distributed Simulation program manages and partially funds the Synthetic Theater of War series of technology demonstrations. The Army's Distributed Interactive Simulation project coordinates the development distributed interactive simulation protocols, standards, and technologies for DoD-wide use.

A 1992 study by the Army Science Board expressed concern that the Army's follow-on programs to SIMNET were fragmented—in particular, that "CATT and BDS-D are being pursued as separate, independent efforts rather than as a single, integrated program. "[2]

[1] E.A. Alluisi, "The Development of Technology for Collective Training: SIMNET, a Case History" *Human Factors,* 33(3)343-362, 1991

[2] U.S. Army, Army Science Board, *1991 Summer Study Final Report, Army Simulation Strategy* (Washington, DC, December 1991), p. 2.

SOURCE: Office of Technology Assessment, 1995.

relearned to rely on artifacts of the simulations may err in real combat. Other critics have questioned the process by which the high-tech simulations have been deemed valid models of combat, saying that the formalized verification, validation, and accreditation (VV&A) process needed to certify mathematical models of combat has been skipped in the case of the high-tech simulations. DoD is just beginning to use DIS for cost and operational effectiveness analyses (COEAs) to justify budget requests to Congress (and within DoD) for system acquisition (156,138,199). When DIS is used for such predictive uses, validation should describe and quantify the uncertainties in the predictions.[4]

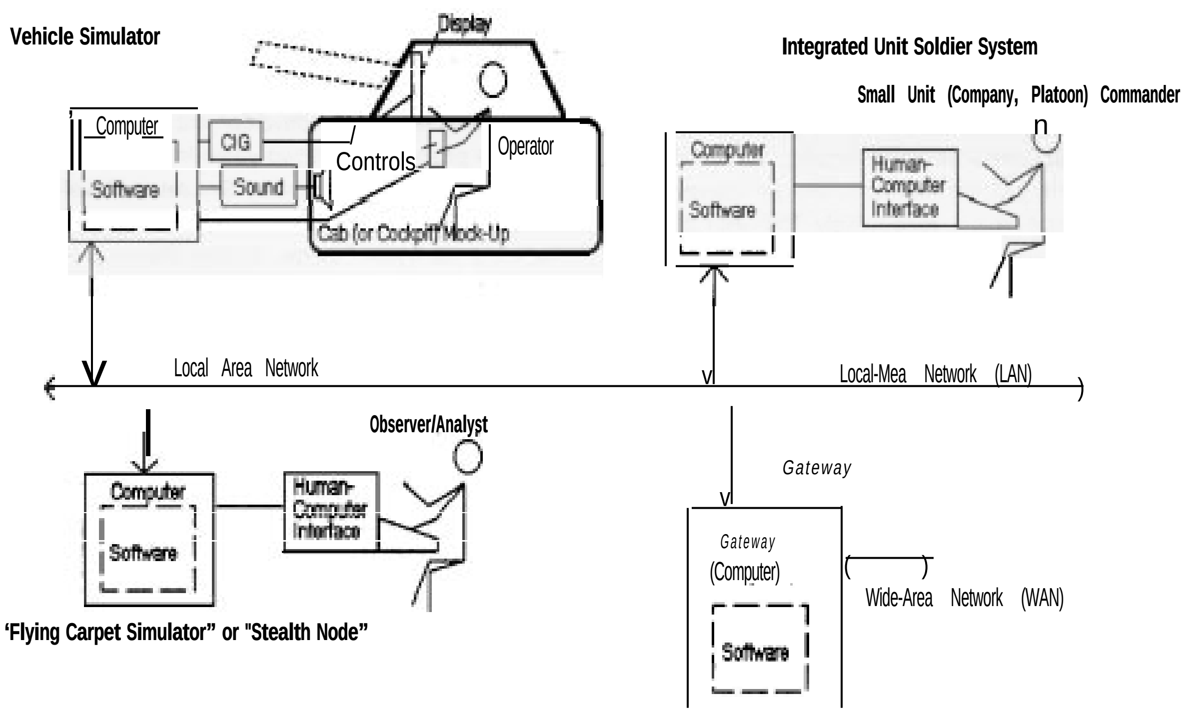
RECENT DEVELOPMENTS

The following DIS-related developments have occurred since the Senate Committee on Armed Services held hearings on simulation in 1992 (145). They are discussed further in either this background paper or a previous one (147). For brevity, this list focuses on, but is not limited to, official activities; there have also been related developments in industry and academia.

1992 Live exercises were conducted at the Wurtsmith Air Force Base Weapon Storage Area to validate the Air Force/Defense Nuclear

[4] For lists of questions or factors to consider in assessing validity, see reference number, p. 281, table I; reference number(135), p. 129; and reference number (197), p. 19, table 2.1.

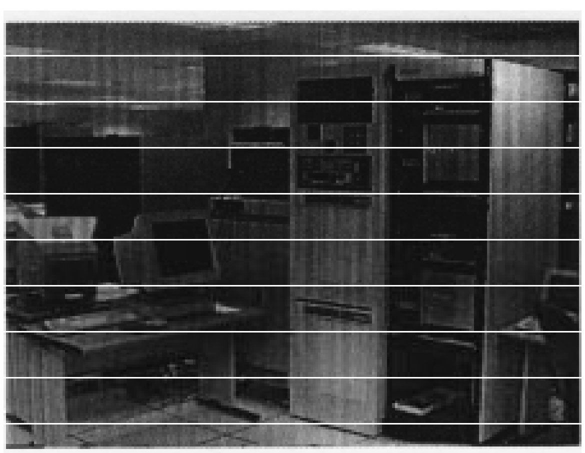
FIGURE 2: Part of a Simulator Network



KEY: CIG = Computer Image generator; LAN = Local-area network; WAN = wide-ares network.

SOURCE: Office of Technology Assessment, 1995.

DEFENSE INFORMATION SYSTEMS AGENCY



Defense Simulation Internet experimental integration area at the Network Engineering and Assessment Facility Laboratory of the Defense information Systems Agency's Center for Systems Engineering in Reston, Virginia.

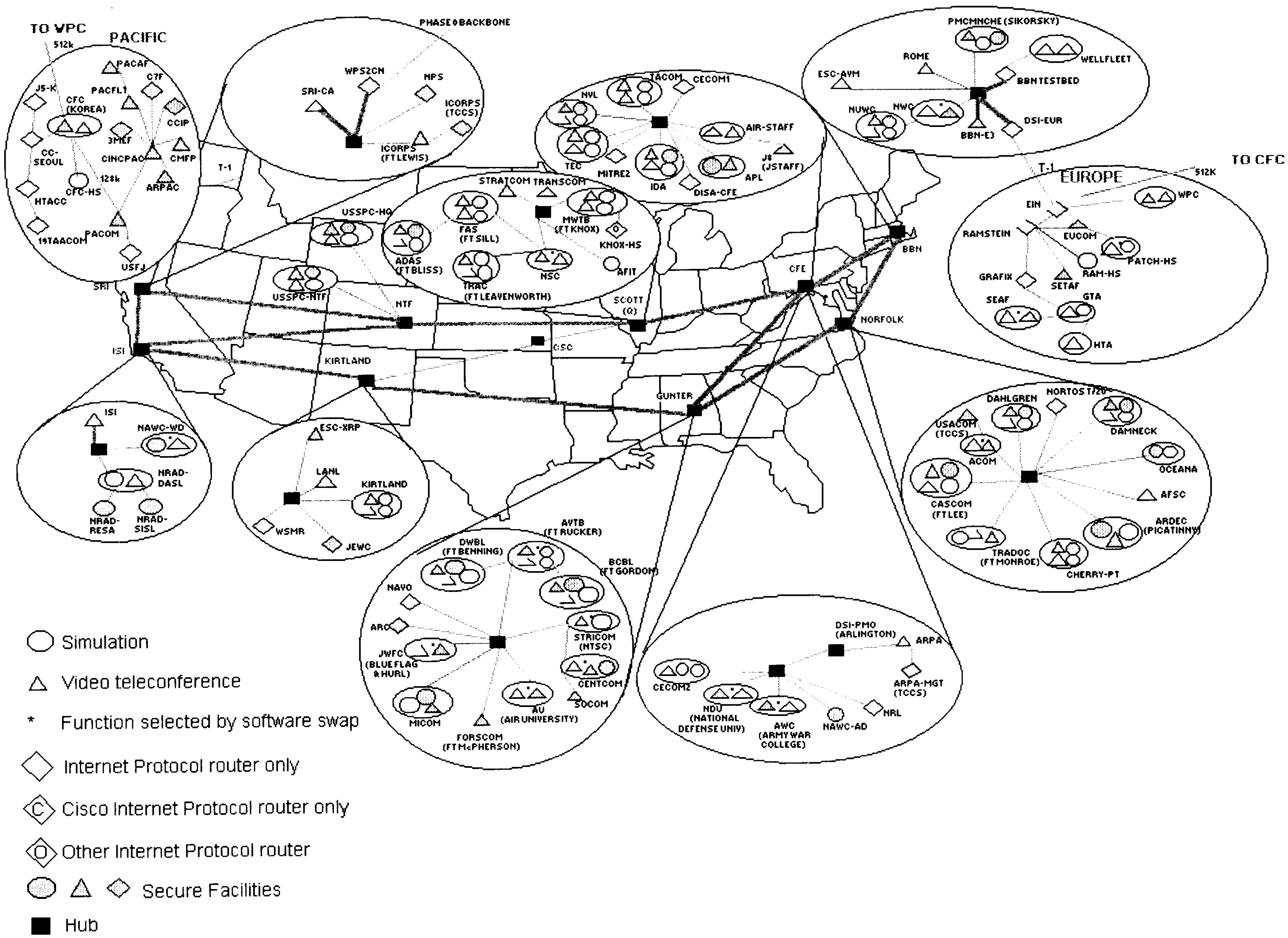
Agency Security Exercise Evaluation System (SEES) (41,141);[5]

1993 Army Pamphlet 5-11, *Verification, Validation, and Accreditation of Army Models and Simulations,* was published;

1994 DoD Directive 5000.59, "DoD Modeling and Simulation (M&S) Management," was issued;

The first *Modeling and Simulation Technology Area Plan (TAP)* was prepared, the first *Technology Area Review (TAR)* was conducted, and the first *Technology Area Assessment* (TAA) was prepared;

[5]SEES version 2.0 is a multi-user, interactive,entity-level constructive simulation, not a distributed interactive virtual simulation. However, the method used to validate SEES version 2.0 could be used with distributed interactive virtual simulations.



SOURCE: Department of Defense, Defense Simulation Internet Joint Project Office, 1994

The first of six planned Anti-Armor Advanced Technology Demonstration (A2ATD) experiments was conducted;

The SIMVAL'94 Simulation Validation symposium was conducted by the Military Operations Research Society (MORS) to address the question, "How Much Verification and Validation Are Enough?"

The Synthetic Theater of War-Europe (STOW-E) exercise was conducted;

1995 The final draft of the *DoD Modeling and Simulation Master Plan* (MSMP) was-completed (195);

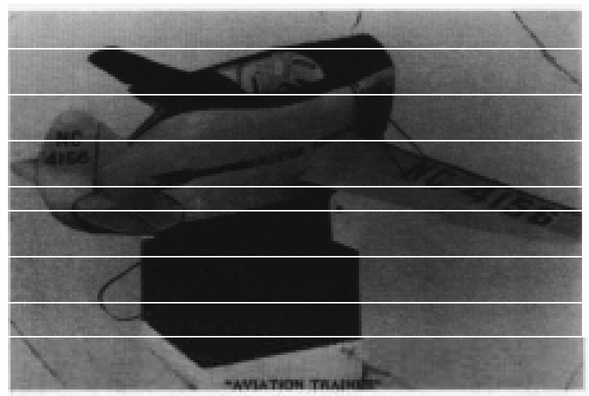
A handbook, aimed at DIS exercise managers, on methodology for VV&A of DIS, is drafted (175);

Proposed revisions of the DIS protocol are discussed at the 12th DIS Standards Workshop; and

An Architecture Management Group (AMG) is formed to steer development of the High-Level Architecture (HLA) called for by the draft MSMP.

SIMULATORS

A simulator is an instrumented mock-up, such as the famous Link Trainer for pilots. The trainee operates the simulator in much the same way that he or she would operate the vehicle (or other equipment) that it simulates. An instructor may program the simulator to present the trainee with particular tasks or problems as the session is underway. Simulators are useful because they are cheaper and safer to operate than the equipment that they simulate.



HUGHES TRAINING INC—LINK DIVISION

The first Link Trainer, built in 1929, used compressed air to make the cockpit move in response to manipulation of the controls.

The variety and sophistication of simulators have increased since the Link Trainer was introduced in 1929, as have the realism and costs of top-of-the-line simulators. The best modem simulators use immense computing capacity and exotic display equipment to synthesize or reconstruct digitally stored scenes, sounds, and vibrations, giving trainees an experience so vivid and realistic that some call it "virtual reality" (182,147). Still, simulators cost less than would the use of real platforms and weapons for training. They are also safer and provide more frequent and varied training opportunities than actual combat does.

Less expensive models lack a motion base (a cab or cockpit platform moved by pistons or electromechanical actuators to provide a kinesthetic sense of being there), but are nevertheless adequate for most training goals.[6,7] For example, the Air Force, following the lead of the Air National Guard, is buying current block F-16C simulators for $650,000 each for use as unit (or unit-level) training tevices (UTDs).[8] They have only a 60-degree vertical by 78-degree horizontal field of view and no motion base, but they cost only $10,000 each per year to maintain—a thirtieth the cost of the most recent simulator—and the Air Force has concluded that they can meet all critical training tasks except 1) post-merge ''fur balls''[9] in air-to-air engagements, 2) multiship tasks, and 3) maneuvers such as ''the pop''[10] in air-to-ground missions (168).

It appears that DoD purchases a very small fraction of the output of the domestic simulator industry.[11] It is likely that most of DoD's purchases for combat modeling and simulation are not counted in simulator sales.

TYPES OF SIMULATIONS

A simulation is a dynamic information construct reflecting some larger reality or possible reality. Its parts and processes correspond to parts and processes of the larger reality, albeit with less than perfect fidelity. In some cases the correspondence involves considerable abstraction. DoD defines a *model* as ''a physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process,'' and a *simulation* as ''a method for implementing a model over time'' (153).[12] DoD also distinguishes three major cate-

[6] A meta-analysis of 26 experiments on flight simulator training effectiveness concluded in 1992 that ''for jet training, motion cuing was found to add nothing to the simulator training effectiveness,'' but cautioned that ''the positive effects of motion for any one task may have been masked by the negative effects of motion for another task'' (60). Similarly, a 1993 study by the U.S. Army Research Institute concluded that no data on training transfer (i.e., effectiveness) supported the use of motion-based simulators, possibly because motion may not help in some cases, or possibly because of insufficient experimentation or shortcomings in experimental technique (8).

[7] The Federal Aviation Administration (FAA) requires a *flight simulator* to have a motion base capable of at least three degrees of freedom (e.g., pitch, roll, and yaw). The FAA classifies an otherwise similar system lacking a motion base and/or a visual system (e.g., a computer image generator (CIG)) as a *flight training device*. An FAA Level 7 flight training device, which must faithfully represent the instruments, controls, and responses of a particular aircraft, can be used for all training for which an FAA Level C flight simulator can be used, less visual and motion aspects. An FAA Level C flight simulator must have a motion base capable of six degrees of freedom (pitch, roll, yaw, heave, surge, and sway). A Level D flight simulator must have, in addition, sound simulation, daylight scene generation with at least 400 edges or 1,000 polygons, and nighttime scene generation with at least 4,000 points of light. Experienced crews can receive training credits in an FAA Level D flight simulator to become type-rated (i.e. qualified) to fly a new but similar type of aircraft with zero flight time. The U.K. Civil Aviation Authority has similar regulations (136).

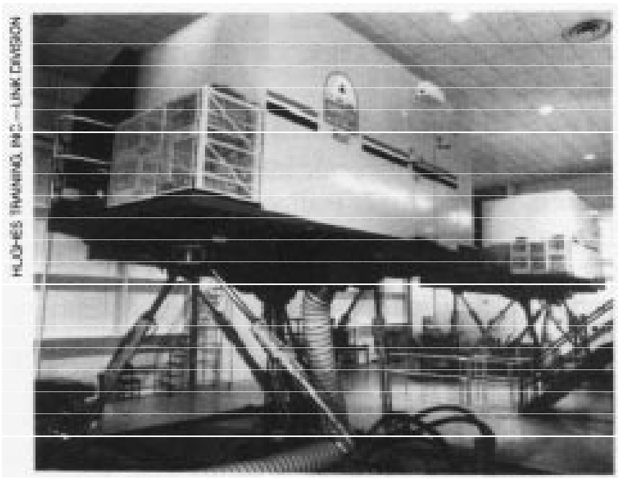
[8] F-15C UTDs cost $750,000 each.

[9] ''Fur ball'' is fighter-pilot jargon for a phase of an engagement of several friendly aircraft with several opposing aircraft in which the opposing groups of aircraft are *merged* (mixed together) and *sorting* (the assignment of targets) is especially difficult.

[10] The *pop*, or *pop-up* is a maneuver in which a strike aircraft that has been approaching its target at low altitude in order to avoid detection suddenly climbs in order to *acquire* (see and identify) and engage the target.

[11] The U.S. Bureau of the Census reported that 1993 sales of electronic teaching machines, teaching aids, and trainers and simulators (product code 36991) totaled $1.1 billion (149). Most of these sales—about $1 billion—were sales of electronic trainers and simulators (product code 36991 81). Electronic teaching machines, teaching aids, trainers and simulators are one of four products produced by the ''electrical equipment and supplies, not elsewhere classified'' industry, to which the Office of Management and Budget has assigned Standard Industrial Classification code 3699, which corresponds to the 1987 Input-Output Account 580500 defined by the U.S. Bureau of Economic Analysis (BEA). OTA's round-by-round analysis (148) of the BEA's unpublished six-digit annual Input-Output tables for 1987 (the last year for which detailed BEA I-O tables were available to OTA) indicated that the federal government puchased, for national defense, less than 1 percent of the industry's output (about $3.5 billion; cf. (45)) directly and less than 2 percent indirectly (double-counting value added in different tiers).

[12] Paul Davis, Corporate Research Manager at the RAND Corporation, considers the terms *model* and *simulation* to be ''essentially synonymous,'' both meaning ''almost any kind of representation of reality.'' He notes that ''few terms are used consistently across communities or even from day to day within a given community'' (24).



A modem Link trainer: the Apache (AI--64) Combat Mission Simulator.

gories of models and simulations (M&S)---live, virtual, and constructive (195):

> Live simulation [is] simulation involving real people operating real systems. . . .
>
> Virtual simulation [is] simulation involving real people operating simulated systems. Vial simulations inject human-in-the-loop (HITL) in a central role by exercising motor control skills (e.g., flying an airplane), decision skills (e.g., committing fire control resources to action), or communication skills (e.g., as members of a C4I team).[13]
>
> Constructive . . . models and simulations . . . involve simulated people operating simulated systems.

DoD acknowledged that there is no clear division between these categories (195):

> The categorization of simulation into live, virtual, and constructive is problematic, because there is no clear division between these categories. The degree of human participation in the simulation is infinitely variable, as is the degree of equipment realism. This categorization also suffers by excluding a category for simulated people working real equipment (e.g., smart vehicles).

Live simulation-humans using real equipment---is the oldest form of combat simulation. Using a rifle to fire live ammunition in a field training exercise would be a pure example--and very dangerous. This photo shows a soldier firing simulated bullets-coded invisible infrared pulses emitted by the eye-safe laser mounted on his rifle, which also fires blank ammunition to simulate the sound of firing. This is a mixture of live simulation and virtual simulation--humans using simulated equipment. The soldier's helmet and suspenders are equipped with sensors to detect coded pulses from lasers on other soldiers' rifles and on other types of weapons. If the sensors detect a simulated bullet, audible and visual signals indicate to the soldier, and to referrees, that the soldier has been hit. The system of lasers and detectors is called the Multiple Integrated Laser Engagement System (MILES).

Live Simulation

Simulations have been used for combat training and rehearsal since time immemorial and for operations research and planning for at least a century. The most ancient and familiar type of combat simulation involves real soldiers, sailors, or, in this century, aircrews operating real equipment—but not in combat. DoD now calls such exercises live simulations.

[13] C4I (or C^4I) stands for Command, Control, Communications, Computers, and Intelligence.

The Army's Louisiana Maneuvers of the early 1940s (44), the U.S. Navy's mock attack on Pearl Harbor just before the real one (100), and portions of recent REFORGER,[14] Team Spirit, and Atlantic Resolve exercises are all examples of live simulation. Most field exercises are scripted in advance.

Though usually a means of training, exercises can be used for research. For example, the Louisiana Maneuvers that preceeded U.S. involvement in World War II taught the U.S. Army important lessons about how to handle large armored formations.[15]

The Army's National Training Center (NTC) offers the most realistic land-warfare exercise environment available today. Instrumented American fighting men and machines, including some playing the role of opposing forces (OPFOR), do battle on a desert battlefield the size of Rhode Island using weapons that fire coded laser pulses instead of bullets. The pulses specify the type of shot simulated, so that a tank receiving a rifle shot knows that it is unhurt, while a tank hit with a TOW[16] antitank guided missile knows that the time has come to simulate its own demise by shutting off its systems and emitting smoke. Training at NTC was given major credit for the success of U.S. forces in the Persian Gulf War.

Live simulation is used by all the services, as well as by the U.S. Unified Combatant Commands and other organizations. Air warfare, naval warfare, amphibious warfare, and joint (i.e., multiservice) and theater warfare are simulated. The U.S. Navy's air combat simulation conducted at Naval Air Station Monterrey, California, was publicized by the motion picture *Top Gun*. Less well known, perhaps, are the Red Flag and Green Flag exercises conducted at the Air Force Fighter Weapons School at Nellis Air Force Base, Nevada, which simulate air-to-air, strike, and surface-to-air combat, as well as electronic warfare. There are many other periodic and ad hoc live simulations.

Military exercises, especially those conducted abroad or on the high seas, serve diplomatic and other purposes beyond their utility to the military. REFORGER and Team Spirit are prime examples in this regard: these periodic exercises help maintain close U.S. ties with the Federal Republic of Germany and the Republic of Korea, respectively.

Constructive Simulation

Prominent historical examples of constructive simulations include exercises on maps and sand tables,[17,18] and games with model ships played at the U.S. Naval War College[19]. Computer-assisted exercises (CAXs) have largely superseded sand-table and map exercises. In some cases they pit a commander (often with staff and subordinate headquarters) against a similarly-equipped human playing the role of an opposing commander. In other cases, there are no humans playing military roles. Instead, an analyst enters data about a

[14] REFORGER stands for Return of Forces to Germany. REFORGER exercises have been superseded, in the post-Cold War era, by Atlantic Resolve exercises.

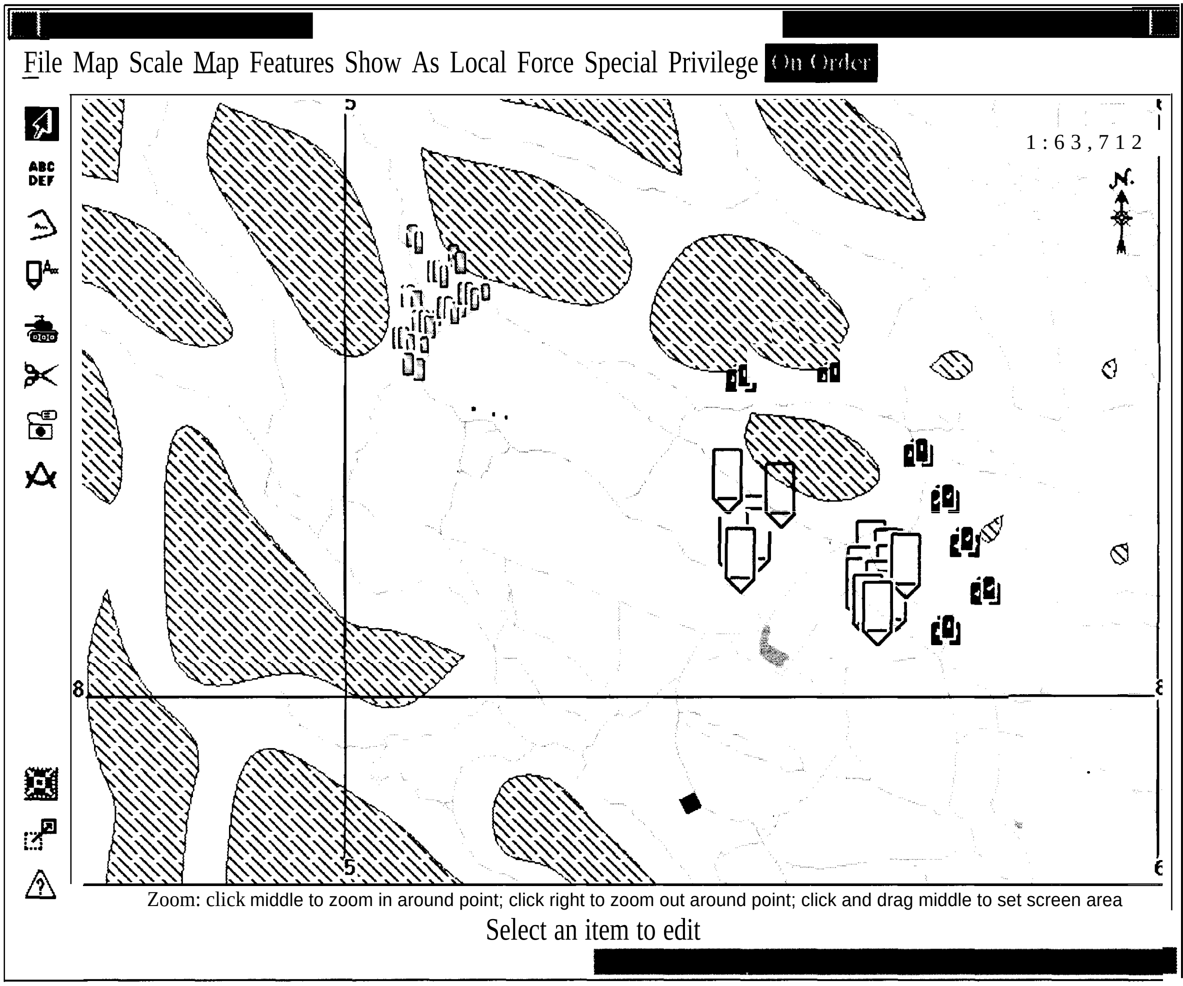
[15] Some years earlier German forces conducted major exercises in the course of developing the Blitzkrieg approach to warfare. Interestingly, these exercises began before tanks were available: crews operated cars fitted with tanklike bodies (17).

[16] A tube-launched, optically tracked, wire-command link guided missile.

[17] These older methods are still used. For example, to visualize and rehearse their part in Operation Desert Storm, one U.S. Army tank battalion commander and his staff maneuvered military models, which they had purchased in garrison in Germany, on Saudi Arabian sand—*sans* table (206). The Army history of the Persian Gulf War shows another example (123).

[18] The Army may use "virtual sandtables" in the future. The Army's Communications and Electronics Command (CECOM) is funding the development of an architecture for a "VR-based dispersed command post. . . , where each commander's virtual environment integrates a virtual conference room containing virtual video walls, battlemap projections, interactive 3D sandtable models, and visual representations of remote conference participants" (47).

[19] See, for example, (105), especially pp. 73ff; (100); and (110) .



This map display shows part of a tank battle being simulated by an early version of the Modular Semi—Automated Forces (ModSAF) software A *constructive simulation,* it simulates movement and combat of individual entities (vehicles and soldiers) and displays the location and status of individual vehicles, as shown here, or small units, such as tank platoons and companies, An operator may be privileged to give orders (e g , move to contact, or move and wait) to various units. Use of ModSAF IS a *computer-assisted exercise* and maybe a *command post exercise* (CPX) for the benefit of unit commanders and their staffs. A computer running ModSAF can participate in a distributed interactive simulation by sending specially formatted messages reporting the location and status of each entity that it simulates, and by processing similar messages from other computers (or manned simulators or Instrumented vehicles) to determine whether the entities or events that they simulate should be displayed or should Influence the entities simulated locally

SOURCE: The RAND Corp., 1995,

real or hypothetical situation into a computer and then instructs the computer to predict, step by step, what might happen, in some cases with resolution (details) of individual vehicles. This, too, is a constructive simulation (see figure 4).

Command post exercises (CPXs) and their naval equivalents, Fleet Exercises (FLEETEXs) exercise only commanders, their staffs, and the communications system. The forces that they pretend to command appear only as marks on a map or chart display. Procedural CPXs are often heavily scripted to insure that certain procedures are rehearsed or tested; scripts may branch at certain points according to command decisions made by

TABLE 1: U.S. Army Command Echelons

Echelon	Notation	Commander's rank[a]
Army Group	xxxxx	General
Army	xxxx	General
Corps	xxx	Lieutenant General
Division	xx	Major General
Brigade	x	Brigadier General
Group/Regiment[b]	¶¶¶	Colonel
Battalion[c]	¶¶	Lieutenant Colonel
Company[d]	¶	Captain
Platoon	●●●	2d or 1st Lieutenant
Squad	●●	Sergeant
Section	●	Corporal
Individual		Private or Private First Class

[a] Typical.
[b] Regiment, if a cavalry unit.
[c] Squadron, if a cavalry unit.
[d] Troop, if a cavalry unit; battery, if an artillery unit.

SOURCES: J.F. Dunnigan, *How to Make War--A Comprehensive Guide to Modem Warfare,* completely revised edition (New York, NY: William Morrow, 1988) ; U.S. Army, *Operations,* FM 100-5, 1986; U.S. Department of Defense, *Common Warfighting Symbology Version 1,* MIL-STD-2525, Sept. 30, 1994

the participants. CPXs are both live and constructive simulations. The participants in one command post (CP) use some of the command and control equipment that they would use in war: field telephones, computer terminals, maps or map displays, and sometimes radios. In this respect a CPX is a live simulation. The equipment connects the CP not only to others in the CPX but also to computers (if a CAX) or referees who perform constructive simulation of the forces that those in the CP command. In a different interpretation, the command and control system is considered to *be* a simulator, not just a means of communicating with one. In this sense a CPX is a virtual simulation. Because it is problematic, if not impossible, to classify a CPX (and other simulations) as live, constructive, or virtual, Paul Davis has proposed a generalized classification scheme, which includes the hybrid classes constructive/virtual (CV), virtual/live (VL), constructive/live (CL), and constructive/virtual/live (CVL) (24).

Simulations of all these types differ from one another in scope, focus, abstraction, and aggregation. One training task will require a particular activity (its focus) to be simulated in detail but can tolerate greater abstraction in the simulation of a related activity, which might be the focus of a different simulation. Concreteness and detail are necessary to make a tank simulator seem realistic to the crew using it, but the simulator need not show forces more than 20 km away or correctly predict which side will win if the only objective of the simulation is to improve the combat skills of participating tank crews. In contrast, both in exercises and war, commanders and their staffs (see table 1) deal, with aggregated forces. They do so through abstraction: an armored battalion, consisting of about a thousand armored vehicles and about 16,000 soldiers at full strength (see table 2), is often represented on paper maps and computer displays at higher echelon headquarters as a rectangle (any unit) enclosing an oval (representing tank tracks, hence armor) with two "x"s on top

TABLE 2: Typical Equipment of U.S. Army Armored Divisions and Mechanized Infantry Divisions[a]

	Armored Division	Mechanized Infantry Division
Transport	3,500	3,500
Soldiers	16,300	16,600
Tanks	348	290
Armored personnel carriers	652	727
Artillery	143	143
Anti-tank guided munitions	523	660
Machine guns	1,360	1,616
Heavy mortars	66	66
Anti-aircraft guns	24	24
Self-propelled SAMs	24	24
Light SAMs	60	60
Anti-tank rocket launchers	900	1,000

KEY: SAM = surface-to-air missile.

[a]This is a simplified table. Terms for vehicles and weapons are not necessarily official U.S. Army terms. Numbers of personnel, vehicles, and weapons approximate those of units at full strength.

SOURCE: J.F. Dunnigan, *How to Make War--A Comprehensive Guide to Modern Warfare,* completely revised edition (New York, NY: William Morrow, 1988)

TABLE 3: U.S. Tank Unit Organization

Unit	Tanks	Soldiers	Subordinate Units
Battalion	33-60	182-540	3 tank companies, 1 headquarters, other units.
Company	10-22	40-88	3-4 tank platoons, 1 headquarters
Platoon	3-5	12-20	3-5 tanks

SOURCES: J.F. Dunnigan, *How to Make War—A Comprehensive Guide to Modern Warfare,* completely revised edition (New York, NY: William Morrow, 1988); U.S. Army, *Operations,* FM 100-5, 1986

TABLE 4: U.S. Mechanized Infantry Unit Organization

Unit	Soldiers	Subordinate Units
Battalion	696	6 companies: 4 infantry, 1 antitank, 1 headquarters
Company	111	3 infantry platoons, 1 headquarters section
Platoon	33	3 infantry squads, 1 headquarters
Squad	9	9 individuals

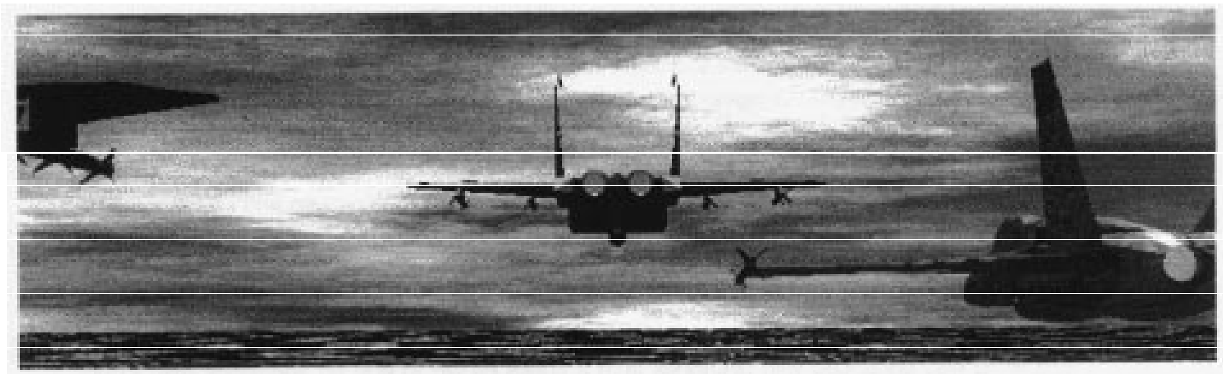
SOURCES: J.F. Dunnigan, *How to Make War—A Comprehensive Guide to Modern Warfare,* completely revised edition (New York, NY: William Morrow, 1988); U.S. Army, *Operations,* FM 100-5, 1986.

(representing the division level of aggregation). An armored battalion, consisting of tens of vehicles and hundreds of soldiers (see table 3), would be represented by the same symbol, except with two vertical bars (instead of two "x"s) on top of the rectangle. A mechanized infantry battalion with about 700 soldiers (see table 4) would be represented by the same symbol, with an "x" (representing crossed rifles) criss-crossing the rectangle enclosing the oval. Messages are equally abstract: "US 1AB" would represent the U.S. Army's First Armored Battalion.

Whatever else they do, combat models model aspects of individual and collective human behavior, such as operational decision making. This modeling has always been controversial, because human behavior cannot be reduced to a set of principles as simple and reproducibly verifiable as those of, say, aerodynamics or solid mechanics, which are used to model and simulate the response of an airplane to a pilot's control actions. Combat is a much more complex and less predictable process, the result of actions by many humans. Of necessity, modeling them requires many simplifying assumptions, often without any scientific justification.

The uncertainty and unpredictability in combat is further complicated today with the shift from a defined superpower confrontation to more complicated and ambiguous tasks for the military. Stuart Starr, Director of Plans at the MITRE Corporation, has observed that because of geopolitical changes in the last 5 years, "models of strategic and high intensity conventional conflicts" are of less interest. In their place, "the M&S community is being confronted with the need to develop credible models of potential crises, humanitarian assistance, and conflicts with

FIGURE 5: Virtual Simulation



This computer-generatad scene is analogous to scenes presented to pilots in flight simulatore. The scene actually illustrates(although not precisely) an episode of live simulation in the November 1994 Synthetic Theater of War Europe exercise, in which U.S. Air Force F-15C *Eagles* and US. Navy F/A-18 *Hornets* practiced joining procedures. Their positions were trackad by the Tactical Aircrew Combat Training System at the Marine Corps Air Station at Cherry Point, North Carolina, end relayed to participating vehicle and radar simulators and constructive simulations.

SOURCE: Office of Technology Assessment, 1995.

and among third world nations. These demands will stress the technology communities' abilities to model human behavior and to represent a broad spectrum of environmental conditions" (131).

■ Virtual Simulation

Some DIS proponents argue that constructive simulations often do not simulate human behavior well, and that the solution to this problem is to put human soldiers (but not their vehicles and weap--ons) back into simulation. Partly for this reason (validity)--but mainly because it was designed to train small units--SIMNET put human soldiers, by the company, into a computer simulation and tried to evoke realistic individual and organizational behavior by presenting them with a realistic, threatening tactical environment, using sights and sounds to raise the tension level as much as conveniently possible (see box 2). The sight-and-sound presentation created by SIMNET is counted by many as "virtual reality" or a "synthetic environment" (see figure 5) (182,147).

Participants in a DIS exercise can get very immersed in the experience. During an early SIMNET exercise, a tank commander dove out of his tank to take a compass reading, as he had been trained and had grown accustomed to get out of a real steel tank in order to get an accurate magnetic compass reading, unaffected by the magnetic effect (permeability) of the tank. When he realized where he was and what he had done, he went back into the simulator (95).

THE EVOLUTION OF DISTRIBUTED INTERACTIVE Simulation

Computer-mediated distributed interactive simulation can be traced to the Air Force's Semi-Automatic [sic] Ground Environment air defense system, which was developed during the 1950s (147). Virtual simulation can be traced to the first Link Trainer, demonstrated in 1929 (147), although rehearsing or playing at war with props for weapons-a form of virtual simulation-is doubtless prehistoric. However, modem distributed interactive simulation began with DARPA's SIMNET program

SIMNET

SIMNET, a billion-dollar (194) development program of DARPA (now ARPA) and the Army, took existing simulation technology and applied microprocessing and networking technology to achieve an interactive simulation. SIMNET simulates the combined arms battlefield, allowing

BOX 2: Human Factors Engineering

SIMNET marked a shift in simulator design from an engineering or physical reproduction approach in the tradition of the Link Trainers and flight simulators to manipulating "brain state" and relying more on human factors analysis. Bringing the psychological realm of human behavior into simulation enabled designers to understand just which sensory cues to give the trainee in order to move his mental focus past the physical mechanism he occupied to the virtual battlefield. "The design did not concentrate on the armored vehicle per se; rather... design became behaviorally driven and began by identifying cues that crew members needed to learn their specific duties and tasks. "[1]

The entertainment industry has long been expert at using just those sounds and sights that engage the imagination of the audience while eliminating any distraction that would break the "suspension of disbelief. "[2] Some of these techniques were used in the SIMNET simulators. For example, the sound of the tank firing was enhanced with overtones from a tiger's growl[3] to add an adrenaline rush to enhance the realism of the simulation.

The difference between the Link-style approach and the SIMNET-style approach is reflected in two different concepts of *fidelity.* Fidelity in the simulation world means much the same thing as it does in the audio world, A "high fidelity" stereo system duplicates the real sound so that it is hard to tell the difference. The effectiveness of simulators has traditionally been measured the same way—by how close the experience felt to the real thing. In SIMNET, however, it was found that fidelity or "accuracy in details"[4] was not necessarily important to achieve immersion that was necessary for teaching skills and sometimes not as effective as specific cueing, a concept the SIMNET team called *selective fidelity.*

Instead of starting with a complete cockpit and subtracting the extraneous components, the SIMNET team started with nothing and built a simulated tank interior based on what they felt they needed to cue a desired behavior. The beginning of the design process was a task list of what skills they wanted to teach. Nothing was added to the design that did not contribute to eliciting some specific, desired training behavior.[5] This approach resulted in a lower fidelity and much cheaper simulator, which made it possible to produce large number of simulators to network together.

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[1] E.A. Alluisi, "The Development of Technology for Collective Training: SIMNET, A Case History," *Human Factors, 33(3): 343-362, 1991.*

[2] J. Isdale, "What is Virtual Reality? A Homebrew Introduction," March 1993, available Online at <URL:ftp://sunsite.unc.edu/pub/academic/computer-science/virtual-reality/papers/whatisvr.txt>.

[3] C. Portman, Hollywood soundman, interview with L. Voss at Perceptronics, Inc., Woodland Hills, CA, August 1992,

[4] *Webster's New Collegiate Dictionary* (Springfield, MA: G. & C. Merriam Company, 1974).

[5] J. McDonough, interview with L. Voss at Illusion Engineering Inc., Westlake Village, CA, August 1992.

forces as large as battalions to fight opposing forces of similar size; it provides an alternative to combined arms field exercises. The network can link hundreds of simulators at widely dispersed sites in real time. By the end of the project almost 300 simulators—Ml Abrams tanks, M2 and M3 Bradley fighting vehicles, aircraft, and command posts (2)—had been produced.

The hardware for a SIMNET-type simulator includes a computer (called a simulation *host),* an image generator, a sound system, and network connections, as shown in figure 2. The image generator is a special-purpose computer that processes the simulation data and generates computer images of the action. The simulation hosts are connected via local- and wide-area networks to other simulators engaged in the same battle. When the tank simulator is networked into a battlefield simulation, the crew see the action of the battlefield in computer-generated scenes through windows or portals at their stations. The actions by their tank simulator—fire and maneuver—are re-

BOX 2: Human Factors Engineering (Cont'd.)

What the SIMNET designers discovered was that faithful reproduction of the physical details of the equipment and even the battlefield visuals were less important than the action itself in engaging the battlefield behavior. Encountering other combatants in a battlefield environment elicited a combative response.

A psychologically different interaction results when trainees become aware that they are working with others on a battlefield, whether cooperatively with a wing man or in opposition with an enemy platoon. The importance is in projecting one's conscious thinking process onto the battlefield.[6]

In SIMNET the battlefield radio communication, group skills, tactics, and plans for engaging the enemy are implemented in real time in an environment that approximates the experience of the battlefield under controlled circumstances. The purpose is to train advanced skills. SIMNET trains soldiers who are already proficient in individual skills (such as driving and gunnery) the next level of skills, which is working together as a unit. At this advanced level, the fidelity of system and environmental representations is less important than the fidelity of the human interaction. Interactive simulation enables soldiers to learn group fighting skills and enables commanders to improve tactical and strategic decision making.

A SIMNET simulator has several video slots, each portraying that part of a battlefield a war fighter would see looking through a corresponding window of a cockpit. Early in the development of SIMNET instructors noted that shortly after the beginning of a simulation session, an experienced war fighter ceases to notice gaps or seams in the displayed scene, because he easily projects out into the battlefield and is absorbed in the experience and the interaction with other people. An inexperienced war fighter, on the other hand, does not recognize the pattern of battle unfolding as easily and remains distracted by the imperfections of the simulation.[7]

It remains a tenet of successor programs, such as the Army's Close Combat Tactical Trainer project, that the important aspect of battlefield fidelity is the percentage of desired behavior learned. This tenet shifts the focus from the machinery to the human interaction.

[6] H. Crooks, interview with L. Voss at Illusion Engineering Inc., Westlake Village, CA, August 1992.

[7] Ibid.

SOURCE: Office of Technology Assessment, 1995.

fleeted in the other simulators, too, and replicated in sound and sight. If one tank is hit by another, the damage is calculated by the tank that was hit and reported back through the network. The image generator generates scenes of the rough geographical features of the battlefield-hills, blue or cloudy skies, trees, houses—and the features of battle---enemy tanks, perhaps hiding behind trees in the distance; smoke and fire; helicopters overhead; and the boom of mortar fire.

SIMNET evolved from a 1979 DARPA project, the tank gunnery trainer (TGT). The TGT was designed to use an Apple II computer to overlay computer-generated imagery (CGI) on background imagery played back from a videodisc. This innovative approach, which was demonstrated in late 1979, promised to provide gunnery practice at a much lower cost than range gunnery practice. The TGTs were expected to cost less than $10,000 in quantity.

In 1981, Jack Thorpe, an Air Force officer, became manager of the TGT program. He proposed networking five TGTs to provide a low-cost platoon-level training device, a *tank **team** gunnery* trainer (TTGT), in which five trainees would be shown the same scene and would compete to be the first to sight and fire at an enemy tank. He also proposed a different type of networking that would permit large numbers of simulators to be networked so that they could interact—e.g., so that the crew in one simulator would see an image of tanks operated by the crews of other simulators moving on the displayed virtual battlefield.[20] In 1982 DARPA awarded contracts directed toward this goal and also approved the SIMNET project, an extension of it focused on Army collective training needs (2).

The first SIMNET contracts were awarded in 1983. At that time the network architecture concept still envisioned generating imagery for each simulator centrally and transmitting it over the network to the simulator. It was soon discovered that this would be too costly, but it also appeared, at least to Thorpe, that microprocessors capable of rendering a simulator's imagery would soon be available and affordable enough to put a computer image generator (CIG) in each simulator. The links of the planned simulator network would then not need the high information-carrying capacity required to transmit imagery; instead, each simulator would only need to broadcast a short message (a packet[21] or datagram[22]) on the network every second or so to notify other simulators of its position and certain other attributes (heading, velocity, turret azimuth, gun tube elevation, etc.). The computer in each other simulator would examine each datagram to decide whether the datagram was from a tank within, entering, or leaving its simulated field of view (2). If so, the simulator's CIG would make the appropriate change in the scene that it displayed.

A breadboard[23] version of the SIMNET CIG was demonstrated late in 1984. In January 1985 a prototype M1 tank simulator, made of plywood, was demonstrated to the Secretary of the Army, the Chief of Staff, Army, and other Army officials. Army interest and funding continued. Later that year two developmental M1 simulators were networked together at the annual convention of the Association of the U.S. Army. By May 1986, two production-model M1 simulators were networked, and by October 1986, eight M1 simulators—two platoons—at Fort Knox, Kentucky, had been networked with computers that represented artillery fire support elements, close air support aircraft, a tactical operations center, and an administrative and logistical operations center. In November 1987, two attack aircraft simulators were added to the net. On simulator displays, these looked like hybrids of A-10 and F-16 aircraft, so exercise participants and observers jokingly dubbed the simulated aircraft ''A-13s,'' because 13 is the average of 10 and 16.

By the end of 1987, the first battalion-level training exercises had been conducted with five air defense simulators and two helicopter simulators added, bringing the total number of simulators at Fort Knox up to 56 fully interactive ground vehicle and aircraft simulators (2). By February 1988, the SIMNET facility contained a total of 71 interactive simulators. Battalion-level force-on-force operational exercises with Forward Area Air Defense elements were conducted in April. A test

[20] In 1978, while working at the Air Force Office of Scientific Research, Thorpe had proposed a similar networking of flight simulators (2).

[21] A *packet* is a physical (e.g., electrical or optical) signal composed of a sequence of pulses, representing 1s and 0s, in a certain order: first a special sequence of pulses (a *flag*) marking the beginning of the packet; then a *header* describing the packet type or format, the *address* of the computer or computers for which it is intended, and in some cases a number used by the receiving computer to determine whether the packet was garbled during transmission; then the *information field* containing the data, message, or message fragment (e.g., a virtual tank's position), which the rest of the packet merely transports; and finally a flag marking the end of the packet.

[22] A *frame* is the information represented by a packet. A frame is a logical object; a packet is a physical (if intangible) object. A *datagram* is a frame used in certain types of networking protocols (standard communication procedures), such as the Transmission Control Protocol (TCP) and Internet Protocol (IP).

[23] In the development of electronic equipment, a breadboard version refers to a prototype that performs the electronic functions required but is not constructed mechanically like the intended product. In the early days of radio development, experimental or hobbyist radio equipment was often constructed by mounting components on a breadboard borrowed from the experimenter's kitchen (or on a wooden board of similar shape), instead of a more costly steel or aluminum chassis of the type used for commercial and military equipment.

of long-haul networking the next month was successful. By the fall of 1989, six SIMNET sites or nodes had been established at Fort Knox; Fort Rucker, Alabama; Fort Benning, Georgia; and European sites (2).

At these sites, four-man tank crews took their stations inside simulators built to look like tanks on the inside (as shown in figure 1-1). The crew members operated switches, knobs, levers, and other controls replicating the controls in a real tank of the type being simulated. Through the simulated periscopes and gunsight, they saw scenery, including simulated vehicles, pass by as they drove or traversed the turret.

Each simulator simulated the dynamics of a tank's engine, transmission, drive train, and suspension: the scenery would pass more slowly when the simulator ascended a hill (because tracked vehicles slow down on a grade) or traversed a muddy field (because tracked vehicles slip or bog down in deep mud). In addition, sometimes the gun or engine would fail to work, because unreliability was simulated, as was damage to electrical, hydraulic, weapons, and other systems. The virtual vehicles broke down, consumed fuel, and expended ammunition at rates calculated from experience with real vehicles.

Computer Image Generation

SIMNET gambled on, and successfully exploited, breakthroughs in computer image generation. In the 1960s, DARPA sponsored head-mounted display research that would find application in future flight simulators (147). In the 1970s high-resolution CIGs in flight simulators projected wide-angle views that followed the movement of the pilot's eyes on a dome above the pilot's head. Computer-generated imagery was used in the Advanced Simulator for Pilot Training (ASPT) in 1976; in the Visual Technology Research Simulator at the Naval Training Systems Center (NTSC) in Orlando, Florida (now the Naval Air Warfare Center Training Systems Division), and in the Unit Conduct of Fire Trainer (UCOFT), a full-mission tank simulator (2).

The TGTs used in the TTGT were simulators with a handle with triggers on the front and an eyepiece through which to view scenes played back from a video recording. The five trainees in the TTGT would be shown the same video-disc-generated scene and compete to be the first to fire on an enemy tank (18). Random access video, in which the trainee could change direction and get a different view (provided it had been prerecorded), was the next step. But even random access video disc technology, in its infancy in 1979 (18), was not flexible enough for interactive training. All the possible images could not be recorded in advance on video. They had to be generated as needed by the computer. CIG seemed integral to accomplishing interactive simulation.

However, during the late 1970s CIG cost $2 million to $3 million per channel,[24] and CIG-based trainers ranged from $5 million for UCOFT to $30 million for ASPT (2). For SIMNET simulators, the concept was to have the simulator's microprocessors project the appropriate moving image for each member of a tank crew. This required eight different views or CIG channels for each SIMNET tank simulator. Lower cost became imperative.

By the end of the SIMNET project, the cost of each visual display subsystem was less than $100,000 (2). The 20- to 30-fold cost reduction from the cost per CIG channel in the early 1970s is partly attributable to the decline in cost and the increase in scale (i.e., number of transistors) of integrated circuits during that period. It is also partly attributable to the fact that each display system (periscope or gunsight simulator, called a *vision*

[24] ''Channel'' or ''visual channel'' when used with respect to [computer-generated imagery] systems, implies one computing entity, often part of several, which processes image data for that part of the simulation presented visually through a display system. Such parts may be one of several elements of the outside visual scene. . . the greater the number of. . . channels, the larger the potential. . . [field of view] provided by the display system'' (136).

block) for which a SIMNET CIG generated imagery displayed fewer pixels[25] than did a typical flight simulator display. This could be justifed because a tank crewman looking through a periscope has a smaller field of view than does a fighter pilot looking through a canopy. (A SIMNET tank simulator did not provide an open-hatch view for the commander.)

Today, as competition continues to drive the costs of computer image generation down, the compromise on resolution is being reversed: newer simulations are using increasingly higher resolution graphics to serve other uses besides training. A 1992 Defense Science Board summer study of simulation, readiness, and prototyping concluded that CIG technology advances would be driven by the commercial sector in the near future (191). Performance and resolution of high-end graphics work stations are increasing, and cost is decreasing. Advances by the consumer electronics industry and video game producers are creating widespread benefits for the visual display market, including better and cheaper image projection systems and liquid crystal displays, which are used in head-mounted displays for flight simulation, surgery, and automotive repair, and in infrared scopes such as those used in the Persian Gulf War (33).

The fidelity of simulated scenes depends not only on the types of phenomena modeled but also on scene complexity and display resolution. Most image generators represent surfaces (e.g., terrain) as connected polygons (e.g., triangles), so the number of polygons in a scene is a measure of scene complexity. Rendering a more complex scene takes longer, so a more useful performance metric is polygons per second, calculated by multiplying the scene complexity in polygons by the frame rate in Hz (147).

The image generator used in the developmental SIMNET M1 tank simulator could render scenes at 120 thousand polygons per second[26]—thus it was named the 120T CIG (98). Its frame rate was 15 Hz (2), so it rendered scenes composed of 8,000 polygons. This composite was divided among eight channels—one for each vision block. There were three vision blocks for the driver, three for the commander, and one for the loader, each displaying an image 320 pixels wide by 128 pixel high, and a higher-resolution vision block for the gunner (98).

Production models of SIMNET simulators used GT100-series CIGs produced by BBN Delta Graphics, as was the 120T. The GT100 series included the GT101, which was equivalent to the 120T; the GT102, which was equivalent to two 120Ts and was usable for 16 channels or for eight higher-resolution channels; the GT110, which was equivalent to 10 GT101s; and the GT120, which was equivalent to two GT110s (98).

Each CIG had to store an object representation—information about the shape, size, texture, and pigmentation—of each type of simulated vehicle participating in the simulation; it also had to store representations of the terrain, vegetation, and cultural features (buildings, roads, and bridges, etc.). Terrain elevation information was organized into load modules each representing a 500-mi^2 patch of terrain as a surface composed of 32 triangles (which are polygons). Each CIG could store 196 load modules at one time in memory—enough to represent a square 3.5 km on a side. Each simulator was required to display ob-

[25] *Pixel* (or *pel*) is an abbreviation for picture element—a dot on a display screen. For comparison, a Super VGA (SVGA) computer monitor can display an image 1,024 pixels wide by 768 pixels high.

[26] For comparison, the current state of the art in commoditized systems is illustrated by the capabilities of the fully scaled-up Silicon Graphics, Inc., Onyx Reality Engine 2 (over 2 million triangles per second (129)) and of the Division, Inc., Pixel Planes 6 system (4 million photo-textured (147) or 5 million Gouraud-shaded (147) triangles per second (28)). Considerable scaling will be required to meet the rendering requirements that ARPA has specified for its Simulation-Based Design (SBD) project: 30 million polygons at 30 frames per second, or 300 polygons per second (147).

jects and terrain out to a range of 3 km, so when a simulated vehicle moved 500 m in one direction, it would load into memory the load modules representing the next row of 500 mi^2 terrain patches beyond those already represented ahead of it, overwriting the load modules representing the row of 500 mi^2 square terrain patches that it was leaving behind.

Typically the heights of the vertices of the triangular patches of terrain were elevations at 125-m intervals. Representing coastlines and rivers in a recognizable form required using elevations at smaller intervals, which the CIG could accommodate as long as each load module contained no more than 32 triangles. A terrain patch that included a coastline might use most of its 32 triangles to represent the coastline and would need few to represent the ocean.

Synthetic Environments

Terrain Database Construction

Battlefield interaction takes place on complex terrain, and the virtual terrain of a synthetic environment should reflect its important features. A tank commander's view of the battlefield is very different from that of a pilot, and tank commander's requirements for detail in terrain representation are different. Having a full field of view is critical for pilots; providing it requires a terrain database and a means of rendering and displaying the scene that the pilot would see, whatever the direction of his gaze. A tank driver, on the other hand, needs only the restricted field of view provided by his vision block; however, his tank simulator needs to know soil properties that affect traction. Ideally, the behavior of the soil should also be simulated. For example, if wet or sandy, the soil should develop ruts if many tracked vehicles traverse it.

A significant indirect cost of the use of computer image generation is the digitization of terrain data for use as terrain databases. Those databases contain all the information about a piece of land necessary for the computer to project hills, trees, and other features combatants would need to see. A terrain database describing Fort Hunter Liggett, California, has been widely used for DIS demonstrations because of its availability and detail.

Rapid construction of terrain databases is needed for mission rehearsal on a contingency basis for two DoD programs in particular: the Advanced Research Projects Agency's Warbreaker program (see box 3) and the Air Force's Special Operational Forces Aircrew Training System. The Air Force requires the capability to rehearse, in simulation, for a mission anywhere in the world with only 48 hours advance notice, using a site-specific (not just typical) terrain database representing 500,000 nmi^2 with photographic texture in multiple levels of detail (89). DoD's draft MSMP contains a number of goals for rapid terrain database generation, including a requirement to ''demonstrate an initial capability in FY 1996 to produce, within one week, standard terrain data to meet M&S functional area requirements contained within a nominal 2,500 km^2 area,'' and a requirement to ''demonstrate in FY 1997 the capability to produce standard terrain data to meet modeling and simulation functional area requirements contained within a nominal 2,500 km^2 area (with three-dimensional terrain, including three-dimensional man-made features, reasonably attributed), within 72 hours'' (195).

The Undersecretary of Defence for Acquisition and Technology has recently appointed the Defense Mapping Agency's Terrain Modeling Project Office to be the modeling and simulation Executive Agent for terrain modeling, to be responsible for meeting the requirements for terrain database generation set forth in the MSMP.

Cartography, the depiction of the three-dimensional Earth in two-dimensional media, has been revolutionized by the use of airborne and space-based remote sensing imagery. Remotely sensed data, unlike ground survey data, provides multidimensional views of terrain using multispectral scanners, infrared cameras, imaging radars (36,198), and photography. Another revolution has been in the direct use of digital terrain. The ultimate product of cartographic data need not necessarily be a paper map. The raw electronic digital cartographic information can be directly used and

BOX 3: Warbreaker

The Advanced Research Projects Agency's Warbreaker program focuses on finding and destroying time-critical targets, including tactical ballistic missile launchers, such as those that launched Scud missiles during the Persian Gulf war. The program is a part of DoD's Precision Strike Initiative, Like the Air Force's Semi-Automatic Ground Environment air defense system[1] and some subsequent projects,[2] Warbreaker uses DIS to simulate a complex system of systems: the weapons, sensor, intelligence, and vehicle systems that must work together to destroy critical mobile targets, The first step of the program was to recreate in simulation the systems and vehicles involved in targeting Scud missiles, modeling their limitations as well as their capabilities. The next step is to improve the process for a more successful outcome.

The objective of the program is to change system design, acquisition, and training in this particular area by evaluating a mix of existing and potential systems to determine how they can operate together more affordable and efficiently and to identify new technologies needed to accomplish the task. The technologies that will be developed to accomplish the mobile targeting include end-to-end integration of data collection, targeting technologies, and allocation of resources for strike.[3] Technologies that will be exploited include those of data fusion, battle management, and intelligence collection, processing and distributing. Connecting national assets to theater-level targeting systems that support mobile and fixed target acquisition is a part of the design.

The program is part of a Distributed Defense Simulation testbed[4] that serves several larger objectives as well. ARPA hopes to use the Warbreaker infrastructure as a procurement tool that brings together the technologist, the developer, and the user for increased effectiveness in weapon systems development and procurement, Warbreaker will also establish a platform for integrating and networking existing systems more effectively. Ultimately, the goal is to establish a DoD-wide multilevel secure DIS infrastructure in which diverse simulations and simulators can be networked into a scenario.

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[1] J.F. Jacobs, *The SAGE Air Defense Systems: A Personal History* (Bedford, MA: MITRE Corp., 1986)

[2] An example is the simulated interoperation of the U.S. Air Force's Tactical Air Control System and U.S. tactical air defense systems with air defense systems of the North Atlantic Treaty Organization. See J.E. Freedman and S.H. Starr, "Use of Simulation in the Evaluation of the IFFN Process, " in North Atlantic Treaty Organization Advisory Group for Aerospace Research and Development Conference Proceedings No. 268 (AGARD-CP-268), presented at a Meeting of the Avionics Panel, Paris, France, 15-19 October 1979.

[3] U.S. Department of Defense, Defense Advanced Research Projects Agency, "Warbreaker (Critical Mobile Targets) System Engineering and Integration Research and Development," preproposal conference presentation, Arlington, VA, Apr. 6, 1992).

[4] U.S. Department of Defense, Defense Advanced Research Projects Agency, Advanced Systems Technology Office, "Distributed Defense Simulation for System Engineering in the Acquisition Process: The SERCES and the Warbreaker Programs," industry briefing paper (Arlington, VA: 1992).

SOURCE: Office of Technology Assessment, 1995,

imbedded within other systems (96). Direct digital data are used for navigation and routing, but for many uses a map is more informative than any picture could be.

Three-dimensional terrain databases have been generated from photographs in two weeks using four weeks of manpower. Overhead imagery can be turned into three-dimensional scenes showing key buildings, topography, and important features for military operations including telephone poles, power lines, and roads (37). Digital information on troubled areas is increasing, and techniques for direct use of remotely sensed data are improving (97). The final step will be to learn to feed that information directly into targeting weapon systems.

Challenges for terrain database generation include the need to combine data collected by a variety of sensors and stored on various media in a variety of formats and security classifications (146). Timely collection of terrain data is also a challenge. One of many technologies that might be useful is airborne or spaceborne interferometric synthetic-aperture radar, which can collect elevation data even at night and through cloud cover (36,198). A different type of challenge is updating terrain database in real time to represent changes in the terrain, such as cratering, that should occur as a consequence of simulated actions, such as barrage or bombardment (147).

Although technological advance is increasing scene rendering detail and speed, it does not yet satisfy the most demanding requirements for terrain detail and extent, such as for strike mission simulation and simulation-based design of complex systems such as ships (147). This is a critical issue in real-time interactive simulation as is terrain database correlation (agreement of the databases, describing the same real or synthetic terrain) among different simulators. Terrain database correlation problems are as old as DIS (in the generic sense of the term), having occurred in the development of the Air Force's Semi-Automatic Ground Environment air defense system (76) and in numerous subsequent cases.

Other Synthetic Environments

The draft MSMP includes action items intended to fulfill the objective of providing timely and authoritative representations of the natural environment—including the oceans, the atmosphere, and space, as well as terrain. Modeling these environments was not essential in the early days of SIMNET, when it was sufficient to fight simulated tank battles at high noon on clear days. Expansion of DIS to accomodate joint exercises involving a greater variety of platforms and sensors (acoustic, radio, infrared, and optical) set in various climates and times of day has made it imperative to model many aspects of the environment—not just terrain. The Undersecretary of Defense for Acquisition and Technology has recently appointed Executive Agents for modeling the oceans, the lower atmosphere, the upper atmosphere, and outer space, to be responsible for meeting the requirements for terrain database generation set forth in the MSMP.

Semiautomated Forces

Realistic collective training of an Army unit requires simulation of some situations in which the unit is greatly outnumbered by opposing forces. It would be expensive if all the opposing forces were virtual forces—soldiers, perhaps experts in foreign force doctrine, operating simulators. To avert this cost, DoD has developed, and is improving, automated computer-generated forces (CGF) and semiautomated forces. Using automated or semiautomated opposing forces allows a simulation to populate the virtual battlefield with a larger number of enemy troops (and perhaps neutrals and noncombatants) and to test proposed doctrine and tactics on a larger scale. SAF were required to simulate large-scale battle exercises for command training, such as REFORGER (see box 4). However, the effectiveness of using an automated force, is limited by the realism of its behavior. The original SAF simulation in SIMNET was rudimentary, but the technology is being improved by efforts such as the Advanced Research Projects Agency's Intelligent, Imaginative, Innovative, Interactive What If Simulation System for Advanced Research and Development (I^4 WISSARD) program.

Current problems and limitations in semiautomated forces include the number of control personnel required to manage SAF in an exercise and the realism of SAF behavior. The goal is SAF that are so capable that the operator of a simulator will be unable to tell the difference between SAF and forces controlled by other manned simulators. Different types of entities (tanks, fighter planes, and dismounted soldiers, for example) pose different challenges for simulation.

Efforts towards this goal are resulting in a shift from SAF that are algorithm-based (as in SIMNET) to SAF that are based on AI (artificial intelligence). In the original algorithm-based SAF, the computer would move each vehicle step by step based on its next objective. Each tank stays in formation with other tanks and avoids obstacles.

BOX 4: REFORGER

Milestones in distributed simulation were achieved during the 1992 REFORGER exercise. In previous years the annual exercise had deployed thousands of troops in Europe. In 1992 much of the action was simulated by networking and interoperating the Air Force's Air Warfare Simulation and the Army's Corps Battle Simulation using a new translation protocol, the Aggregate Level Simulation Protocol. The Aggregate Level Simulation Protocol synchronized the timing of events in the two constructive simulations and relayed event and status messages from each to the other, so that the results of one could influence the other, '

Perhaps the most significant feature of the exercise, however, was the saving of $34 million over REFORGER '88. REFORGER '88 had deployed 17,500 people; REFORGER '92 deployed only 6,500 people, but simulated the actions of 175,000 people, including the semiautomated forces controlled by 200 experts at Fort Leavenworth, Kansas. The post-exercise review concluded that the training accomplished in REFORGER '88 was negative for lower-level troops,[2] who mostly sat at roadsides, and minimal for command staff. REFORGER '92 had fully documented, free-play interaction resulting in positive training at all levels. However, because REFORGER '92 was live at the command post level but constructive at the soldier level, fewer soldiers were trained than in 1988, This is an improvement only if one accepts the proposition that the negative learning by soldiers in REFORGER '88 outweighed the value of any positive learning at that echelon. Another way to summarize the results: REFORGER '92 demonstrated the potential of constructive simulation to save money and other resources in providing realistic command and staff training in the context of a large-scale scenario, but it was not designed to provide realistic training opportunities for individual soldiers.

[1] Earlier in 1992, in the annual Ulchi Focus Lens exercise, the Aggregate Level Simulation Protocol had linked computers running the Corps Battle Simulation in Korea with computers running the Air Warfare Simulation and the Navy's Research, Evaluation and Systems Analysis model at the Warner Preparation Center in Germany. Later, a constructive Marine Corps simulation was added to the confederation of simulations that could be linked by the Aggregate Level Simulation Protocol. See MITRE Corporation, *Aggregate Level Simulation Protocol (ALSP) Program Status and History* (McLean, VA: March 1993); available online at <URL:http://alsp.arpa.mil/alsp/89-92-history/89-92-history.html>.

[2] U.S. Department of Defense, Office of the Undersecretary of Defense for Acqusition, Defense Science Board Task Force on Simulation, Readiness, and Prototyping, *Impact of Advanced Distributed Simulation on Readiness, Training and Prototyping,* condensed (Washington, DC: January 1993).

If the lead tank sees an obstacle and changes direction, the next tank may slowdown to avoid a collision. As the lead tank moves around the obstacle and gets back on course, the second tank has to readjust to get back in formation. Multiply these decisions by 16 tanks and the result is sometimes erratic behavior.

This control base has been improved with a concurrent control base that takes the same goals and arbitrates them using weighted distributions for each goal in an ongoing balancing of the directive for the tank. Using this "fuzzy logic" method, also, additional objectives for a mission scenario can be added to the code for a more complex response.

The next step up in complexity is knowledge acquisition by the SAF using techniques of artificial intelligence, including expert systems and case-based reasoning. Expert systems are developed by *knowledge engineering:* interviewing an expert (e.g., a pilot) to discover the rules of thumb and information he or she uses to solve a problem, then putting that information into the software in a form that a computer can use to direct action. This is a laborious process. An alternative is case-based reasoning: designing SAF software that can learn

BOX 4: REFORGER (Cont'd)

	REFORGER '88	REFORGER '92
Deployed troops	17,487	6,500
Engaged troops	more than 97,000	more than 20,000
Engaged tracked vehicles	7,000	135
Engaged tanks	1,080	0
Simulated troops	more than 97,000	175,000
Simulated tracked vehicles	7,000	12,810
Simulated tanks	1,080	1,950
Maneuver HQ	35	41
Exercise scale	corps vs. corps	army group vs. front
Style	umpire	free play, intelligent opposing force
Intelligence play	scripted	sensor level feedback
Training effect (battalion and below)	negative (on roads)	positive (at home station)
After-action review	anecdotal	analytic data
cost	$53.9 million	$19.5 million

SOURCE: Office of Technology Assessment, 1995.

from its own successes and failures in simulated combat. For the computer to "learn" from experience, it must be able to acquire knowledge from new experiences in real time and add it to its knowledge base (i.e., expertise) in such as way as to be able to use it later. The computer's knowledge base consists of many cases that the computer uses in real time to match the scenario it is dealing with and respond accordingly. If the computer sees something new, it is added to the database. Case-based reasoning is the basis for machine learning in 1[4]WISSARD (142).

Currently, such added case-based learning is coded in by hand after an after-action review. Ideally, a computer could do such a review automatically in realtime. A pilot could train the computer by dogfighting with it. If the pilot performed a maneuver that the machine had never seen before, the computer might be killed but would add that trick to its knowledge base. If the pilot tried to repeat his success, he would find that the computer does not respond in the same way. The scenario would turn out differently. This could provide a richer training experience for the pilot and make the simulator training useful longer.

Simulation Architecture

The DoD's draft Modeling and Simulation Master Plan defines *architecture* as "the structure of components in a program [or] system, their interrelationships, and principles and guidelines governing their design and evolution over time" (195). It calls for the development of a comprehensive, abstract *high-level architecture* for DoD simulation: "the major functional elements, interfaces, and design rules, pertaining as feasible to all DoD simulation applications, and providing a common framework within which specific system architectures can be defined" (75,167).[81] The current, still evolving DIS architecture evolved from that of SIMNET.

When the SIMNET program began, most simulation data processing was done by a central

[27] Examples of specific system architectures are the proposed Communications Architecture for Distributed Interactive Simulation and the object and event architectures embodied in the Distributed Interactive Simulation protocols.

computer.[28] Initially SIMNET was envisioned to use a similar architecture: control inputs from several simulators would be transmitted to a central computer, which would process the data and send video signals back to display systems—television receivers—in all the simulators. Each simulator would require several television channels—one per simulated periscope or gunsight—and it was soon realized that a cable from the central computer would only be able to serve a few simulators. The architecture was not *scalable*—that is, the number of networked simulators could be increased eonomically.

SIMNET's program manager, Jack Thorpe, invented a different, more scalable architecture. Each simulator would be designed to do its own simulation processing and image generation. Each simulator was to be a self-contained unit, with its own host microprocessor, terrain database, display and sound systems, cockpit controls, and network interface. Each would generate all the sights and sounds necessary to train its crew. Each tank crew member would see a part of the virtual world created by the graphics generator using the terrain data base and information arriving via the net regarding the movements and status of other simulated vehicles and battle effects—the precise part being defined by the crew member's line of sight: forward for the tank driver or from any of three viewing ports in a rotatable turret for the tank commander.[29]

With the shift from centralized processing to autonomous, distributed processing, the concept of data communication changed. Each simulator was to communicate with every other simulator instead of with a central mainframe computer.[30] In addition, each simulator is responsible for what it represents on its displays. Each simulator's microprocessor carries a model for all of the objects on the network, including itself, that describes that object, its state, and activity and is responsible for updating that model when something changes.

In order to overcome the problem of massive amounts of data exchange, the SIMNET team decided that constant updates were not necessary, only significant changes needed to be communicated. In between, the simulator projects other objects, based on its internal model and assuming there is no change, according to its last information: if a tank is traveling a particular direction at a certain speed, a SIMNET simulator projects the vehicle continuing on in that direction at that speed until told otherwise. This way, the action continues between update information and the speed of update merely influences the smoothness of the transition to a new state. A more sophisticated version of this ''dead reckoning'' idea is ''remote entity approximation,'' which incorporates not only first order approximations like velocity, but also second order approximations like acceleration. The key idea behind both dead reckoning and remote entity approximation is the substitution of local data processing, which is easy, for data transmission to each simulator over the network, which is expensive and constrained.

The basic design of the network for SIMNET was set by 1985. Simulators were linked through local area networks onto a larger wide area net, the long-haul network. With that design in mind, the project was divided into three different areas of contractor effort: networking technology, simulator design and manufacture, and computer generated graphics for the simulators.

The wide area network (WAN) that DARPA used for SIMNET was based on a network that had already been developed for them by BBN called the Terrestrial Wide Band Network (TWBnet). DARPA expanded it into a network, called the De-

[28] However, in 1978 the Naval Training Systems Center had converted its mainframe-based simulation processing to a multi-minicomputer architecture, a precursor to distributed processing (2).

[29] J. Thorpe, 1987, cited in (2).

[30] In recent years, as the number of entities in large simulations has increased, this sort of broadcasting has become a bottleneck and has been replaced by a technique called *multicasting*. See the section Scalability And Scaling, below.

fense Simulation Internet (DSI), that could be used by the Defense Department for simulation. (It is also used for video teleconferencing.) Development of the DSI is now managed by the Advanced Information Technology Services Joint Program Office (AITS-JPO), a partnership between ARPA and the Defense Information Systems Agency (DISA) established in 1994. ARPA continues to develop the technology; and DISA will have responsibility for operating the DSI after it becomes operational. In February 1995, the DSI Program Manager (PM), Stuart Milner of ARPA, handed over the program management responsibility to Commander Walt Corliss of DISA, recognizing that the network communications infrastructure had become more stable and reliable. The concentration of the DSI PM has shifted to processes, procedures, and exercise support. ARPA's Real-time Information and Technology Networking (RITN) research and development program will continue to feed new technology into the DSI (69).

The DSI's lines are being upgraded for better communications and continually extended to include more "nodes," or locations where one or more simulators networked together on a local area network (LAN). A LAN connects the simulators at a particular site to one another and to the WAN (the DSI). In late 1994 the DSI had about 100 nodes. Once operational, the DSI will become part of the Defense Information Systems Network (DISNet), which will "migrate" to become part of the Defense Information Infrastructure (DII) and will be interfaced with the Global Command and Control System (GCCS), so that commanders can train "at home" using their wartime command and control systems. DoD's draft Modeling and Simulation Master Plan calls for greater exploitation of wireless technology, including satellite communications, so that forces may participate in simulation even when deployed overseas, and to link live forces into distributed simulations, as was demonstrated in the 1994 STOW-E exercise (see box 5).

The decision to use distributed data processing and the network concept required a new architecture for data communication over the network that would allow information to be passed back and forth between hundreds of simulators fast enough to convey all the necessary interaction in real time. The DIS architecture that evolved is, even more than the computer-generated visuals or the selective fidelity simulators, the great legacy of the SIMNET program.

The DIS architecture is an open architecture based on the International Standards Organization's Basic Reference Model for Open Systems Interconnection (OSI): ISO 7498-1984. The ISO OSI networking standard provides a seven-layer structure that specifies standards and protocols covering everything from the physical network to the data interchange between simulators. There are specific standards for communication over the long-distance network, for electronic communication for each particular type of local area network, and for the particular application, in this case the SIMNET simulation. In terms of this seven-layer standard, the SIMNET protocols are the application layer (the top layer, layer seven) that uses the services provided by the network and data link layers without necessarily requiring services from the intermediate layers (113). The standard provides common rules by which independent users can play on the net.

An important recent development is the establishment, by the Under Secretary of Defense for Acquisition and Technology, of the DMSO Architecture Management Group (AMG) to oversee development of the High-Level Architecture (HLA) called for by the DoD Modeling and Simulation Master Plan draft of January 1995. The AMG's membership was approved by the DoD Executive Council on Modeling and Simulation (EXCIMS) on Mar. 22, 1995, and the AMG held its first meeting on Mar. 31, 1995. Over the course of the next year, the AMG will review and evaluate a series of prototypes conducted to test and further define the architecture. Based on the results of these prototypes and other analyses as necessary, the AMG will prepare a baseline definition of the HLA, which is due in June 1996. This architecture will be recommended to the EXCIMS, who, after appropriate review, will submit it to the Under Secretary of Defense (Acquisition and Technology)

BOX 5: Synthetic Theater of War

Synthetic Theater of War (STOW) is a program managed by the Advanced Research Projects Agency (ARPA). It aims to demonstrate a capability for large-scale (ultimately theater-level) battlefield simulation using advanced distributed simulation (ADS) to combine virtual, constructive, and live simulated combat onto one, interactive electronic battlefield. The program has several objectives: 1) improve the quality of simulations through entity level resolution of combat and environmental representations in simulation, 2) improve simulation training effectiveness and flexible interfaces with operational command, control, communications, computers, and intelligence systems, 3) integrate distributed live, virtual and constructive simulation models, 4) reduce the overhead costs of simulation knowledge based, semiautomated forces, 5) provide faster databases with improved information transfer, 6) improve after action and analysis tools, and 7) provide improved simulation-driven crises rehearsal capabilities to warfighters.[1]

STOW was originally recommended by General Paul F. German and the Defense Science Board in 1992 as one of 12 experiments to prove the usefulness of advanced DIS technology to a variety of DoD organizations responsible for weapon system acquisition and joint warfighting. The project was at first called the Southwest Experiment, because all the military services had instrumented ranges in the southwestern United States that could be linked together to create a joint (i. e., multiservice) synthetic battlefield.[2] The objective was to link several instrumented training and test ranges with simulator sites to test proposed weapons and joint warfare doctrine using live, constructive, and virtual simulation.

In August 1992, Director of Defense Research and Engineering Victor Reis signed a Memorandum of Agreement with the Joint Chiefs of Staff (JCS) to “formulate and pursue” the recommended technology demonstrations. The agreement assured the emphasis on joint war fighting.

Operators reviewed the original experiments, and eventually six categories of demonstrations were funded: the synthetic battlefield, force generation, F-1 6/Joint Electronic Combat Electronic Warfare Simulation, commercial battle games, Special Operational Forces/Joint Task Force integration, and the Warbreaker program, which included demonstrations of technology for Theater Area Missile Defense and for finding and attacking Critical Mobile Targets. The JCS allocated $11.5 million through 1995 for a synthetic battlefield demonstration that would involve all the Commanders in Chief (CINCs) of combatant commands and all the military services.

The Joint Staff Operational Plans and Interoperability Directorate (J-7) joined with ARPA to use the demonstrations to “find practical ways in which ADS can improve joint doctrine, plans, operations, training, and education. ”[3] The alliance combines the resources and operational requirements pull of the CINCs with development of a technology that promises to help satisfy the new initiatives in joint war fighting exercises mandated by Congress with the new East Coast simulation center and the new mission training responsibilities of the U.S. Atlantic Command (USACOM) specified in the Unified Command Plan,

[1] Department of Defense, Advanced Research Projects Agency, Advanced Systems Technology Office, “Synthetic Theater Of War, ” as of May 12, 1995, <URL:http://www.arpa.mil/asto/stow.html>.

[2] Preference for center location later shifted toward South Carolina. USACOM, influenced by the Navy and Marine Corps, preferred South Carolina, where the Marine Corps has a warfare center and the Navy’s Battle Force Tactical Trainer and naval bases are located.

[3] Maj. Gen. A. Rogers, Joint Staff, J-7, presentation, National Training Systems Association conference, Alexandria, VA, March 25, 1993.

BOX 5: Synthetic Theater of War (Cont'd.)

Three major technology demonstrations have been scheduled for STOW, each a milestone marking the end of a phase of the ADS current technology demonstration plan. The first, Synthetic Theater of War-Europe (STOW-E), was conducted from November 4 through November 8, 1994, during, and as part of, the annual U.S. Army Forces Europe JTF exercise Atlantic Resolve '94 (the successor to REFORGER). It demonstrated the linking and interaction of live, virtual, and constructive simulations, and marked the end of phase I of the ADS current technology demonstration plan. About 3,500 entities—aircraft, ships, armored vehicles, etc.—participated. The maximum number of entities participating simultaneously—the "high-water mark''—was over 2,000. The first technical papers reviewing achievements and problems are beginning to appear as this background paper goes to press.[4]

STOW-E stemmed from a request by General Maddox, Commander in Chief of U.S. Army Forces Europe, who, having SIMNET simulators and the live range of the Combat Maneuver Training Center (CMTC) in Germany available, wanted to be able to use the capabilities of simulated training to tie together a SIMNET battalion, constructive forces, and live forces on the instrumented range to do large-scale exercises. In Germany today for political, economic, and ecological reasons it is not possible to maneuver live units larger than a battalion.

In STOW-E, constructive simulations, such as the Brigade/Battalion Battle Simulation (BBS), were linked to the simulation network via a translation unit (called an Advanced Interface Unit or Advanced Translator System), which translated constructive simulation results into DIS-compatible messages. The translators were designed to disaggregate a platoon (for example) that is simulated as an aggregate unit by the BBS into four tanks visible to SIMNET simulators whenever a SIMNET simulator approached the agregated platoon close enough to see one of its tanks. STOW-E also used ModSAF, a DIS-compatible constructive simulation. Translators were also used by the participating field instrumentation systems, such as the CMTC Instrumentation System, to report the locations and status of real vehicles to the simulation network so that representations of them could be seen by simulator crews. Several *bandwidth reduction* techniques-designed to reduce network congestion and permit more entitles to be simulated—were demonstrated in STOW-E.

The next major technology demonstration planned for STOW is Synthetic Theater of War-1997 (STOW-97), to be sponsored by USACOM, focused at the Joint Task Force level, and conducted in 1997, In late 1994, the projected scale of STOW-97 was revised downward from 100,000 entities to 50,000 entities. The third and final major demonstration planned for STOW is Synthetic Theater of War-2000 (STOW-2000), to be sponsored by USACOM and conducted in 2000. It will mark the end of phase Ill of the technology demonstration plan, i.e., of technology insertion and transition to operational systems.

[4] University of Central Florida, Institute for Simulation and Training *12th DIS Standards Workshop Proceedings,* July 14, 1995, available online at <URL:ftp://ftp.sc.ist.ucf.edu/public/STDS/workshop/12th/proceedings/> . See also P. Marion, "STOW-E-First Impressions Report," Nov. 28, 1994, available online at <URL:gopher://triton.dmso.mil.:70/00/twg/dsi/dsi-docs/stow-e.txt>

SOURCE: Office of Technology Assessment, 1995.

for approval. During the course of its work, the AMG will brief DoD's Modeling and Simulation Working Group, which supports the EXCIMS, on its activities (165,166,1 12,180).

Uses and Limitations of SIMNET

SIMNET matured as a company-level simulation and now easily handles battalion-level actions.

The primary controversy surrounding SIMNET is the degree to which it is possible, or even desirable, to create a large battle by connecting SIMNET nodes (and their other-service equivalents, as these develop) together (see e.g., box 6). While intuitively one might think that the whole is the sum of the parts and that therefore with enough SIMNET simulators one could simulate a large battle, other considerations may supervene.

For example, SIMNET focused on tanks and other vehicles, and DIS does not yet handle the individual soldier well. Yet the humble foot soldier, modernly equipped, retains his key role in warfare. The considerable antitank potential of today's infantry makes the foot soldier an important player on the tanks' battlefield and the key to the tanks' survival should they venture into woods or urban areas. The Army's Integrated Unit Simulation System (IUSS) project and Individual Port (I-Port) project have demonstrated that individual dismounted infantry troops can participate in synthetic combat (147), and the Army recently awarded a $1 million contract to Avatar Partners, Inc.,[31] of Boulder Creek, California, for the development of a wireless unencumbered virtual reality system—called Dismounted Infantry Virtual Environment (DIVE)—for infantry training applications. (121) However, it may not be feasible, affordable, or necessary (for some training tasks) to populate a synthetic battlefield with as many dismounted troops as there would be on a real battlefield.

Another problem is that most participants in a battle spend much more time waiting than fighting. Moreover, battle is a stochastic (i.e., random) process—actually, the result of many stochastic processes. To deduce valid results from a simulation, it would be necessary to simulate the stochastic processes[32] and to do so many times, so that typical outcomes and the range of outcomes can be discerned.[33] Considering the hours of inactivity that most trainees would endure in an accurate simulation, it is questionable whether the troops' training time (and simulator time) would be well spent in repeating the same scenario many times in order to estimate the expected outcome (e.g., losses) and the range of outcomes. Perhaps, if the goal were a simulation of a large battle, all of the forces should be semiautomated, not just one side's. Indeed, computerized combat models featuring large forces, in some cases resolved down to the vehicle level, have been available for some time. These include Corps Battle Simulation, Concepts Evaluation Model, Janus, Joint Integrated Contingency Model, TACWAR, etc.[34] SIMNET's graphical interface will be wasted on a higher echelon commander, whose personal point of view will be the inside of a command post regardless of whether the battle is fought inside a computer, in SIMNET, at NTC, or in the real world.

SIMNET's use for large battles has been proposed for two different purposes. One is exercise,

[31] Avatar Partners, Inc., is now called DIVE Laboratories, Inc. DIVE Laboratories, Inc., will also assist General Reality Company in an effort to ''develop a VR-based dispersed command post architecture for military commanders,'' for which General Reality Company was awarded a Phase 1 Small Business Innovation and Research (SBIR) contract from US Army CECOM (47) .

[32] In SIMNET, this is done by letting humans control some processes, such as aiming and firing weapons. Other stochastic processes, such as wind velocity, are simulated by computers using *Monte Carlo* methods—in effect, throwing dice electronically. The result of a roll of a pair of electronic dice is adjusted to give the right average speed and gustiness—i.e., range or standard deviation of speed. For example, the average value rolled by a pair of dice is 7; values range from 2 to 12, with a standard deviation of about 1.71. In order to model a westerly wind with an average speed of 14 knots, gusting to 17.5 knots, one might double the value rolled to get the speed in knots.

[33] The result of a single simulation might be valid in the sense that it *could* occur in reality, but it might be so unrepresentative of outcomes of similar conflicts that one would be foolish to assume that it is a reliable prediction of what will happen, without some knowledge of the range of outcomes that occur in several runs of the simulation and without some evidence that outcomes of comparable real-world situations usually lie within the range of simulation outcomes.

[34] Some of these models were developed at Federally Funded Research and Development Centers (FFRDCs), formerly called Federally Chartered Research Corporations (FCRCs).

BOX 6: BFIT II

At the time SIMNET was being developed, the Navy was working to develop a naval gunnery training system, also, called Battle Force In-port Training (BFIT), later renamed Battle Force Tactical Training (BFTT). The Navy was working on networking ships in port. The Defense Advanced Research Projects Agency (DARPA) combined SIMNET networking technology and simulators with BFIT to demonstrate component interoperability (a first step towards joint warfighting training) the following month in April 1990.

The BFIT demonstration networked a Navy ship, the *U.S.S. Wasp,* in port at Norfolk, Virginia, with Marine Corps SIMNET simulated helicopters at Fort Rucker, Alabama, simulated Army tanks, Navy staff command centers, and an observation node at the Institute for Defense Analyses. The demonstration included a Marine Corps pilot and Army tank commander calling for Navy fire of a Tomahawk missile over simulated terrain (using the Fort Hunter-Liggett, California, terrain database). The simulated Tomahawk mission required command, control, and communication between Navy, Army, and Marine Corps elements to coordinate missile flight through friendly forces to its target. The simulated Tomahawk missile showed up on the Navy radar as did the pilots when they flew over the *U.S.S. Wasp* symbol on their screens. It was the first time the Marine Corps, Navy, and Army played on the same network using their own systems. [1] The joint operation was not completely smooth, but improved with practice.

The demonstration not only illustrated the DIS technology's joint component interoperability, but also illustrated some technical accomplishments and features of the technology. Two valuable features of DIS technology are its modularity and its flexibility. Ultimately, any type of computer system that can do the processing and display can be brought onto the network and added to the interaction (within the limits of the number of sites supported by the networking technology). In the DARPA/Navy BFIT proof-of-principle demonstration the computer consoles were real consoles in real ships, turning real equipment into simulators. This type of simulation, with outputs from simulation interactions used as inputs for the visual displays of real equipment such as sonar and radar screens, is called *stimulation. So* not only were geographically dispersed simulators networked in real time, but simulators designed for interactivity were also networked with real equipment not specifically designed for interactive training. This was demonstrated on a larger scale in the 1994 STOW-E exercise. A milestone yet to come is the routine incorporation of equipment for interacting in simulation (called field *instrumentation* in the DIS community) into platforms such as tanks and airplanes.

[1] *BFIT II Battle Force In-Port Training 1992* (videocassette), VO 92030, U.S. Navy, Naval Ocean Systems Center, CA, 1992.

SOURCE: Office of Technology Assessment, 1995.

the other is simulation. At present, the large computerized combat models are used in these ways. In command post exercises CPXs they determine the combat outcomes resulting from the commanders' decisions. As simulations, they are used to develop answers to questions such as force sizing and deployment. In the latter vein, one possible use of SIMNET is "virtual prototyping, " in which a candidate weapon would take its place on the simulated battlefield before it is even produced, so that its utility could be evaluated prior to the effort and expense of production.

SIMNET proponents argue that the older combat models lack the humans necessary to simulate human behavior. SIMNET is constructed to present its trainees with a realistically threatening environment, using sights and sounds to raise the tension level as much as conveniently possible. The sight-and-sound presentation created by SIMNET is counted by many as "virtual reality" or a ‘‘synthetic environment.’’ Therefore, it is argued, SIMNET forces will display behavior more human than the behavior programmed into the forces that inhabit pure computer models.

This point begs the question of whether the SIMNET players, regardless of how tense, aggressive, or scared SIMNET can make them, will really behave as they would if they were in mortal danger. A related question, which is important in simulations conducted for research (rather than training), is whether the participants are as qualified, trained, and experienced, as will be those who would fight a real war. This issue is not peculiar to DIS; it has been raised earlier in the context of CPXs, other constructive simulations, FLEETEXs, and crisis simulation games, many of which (for various reasons, including training) are played by participants much less experienced or distinguished than those they attempt to emulate.

The argument that human participation is necessary for realism seems difficult to reconcile with acceptance (by proponents of that argument) of the use of CGF. If the CGF don’t behave realistically, the battle is only half-realistic in this regard, and if they do then CGF could be used as friendly forces, in simulations conducted for research or the provide realism and context in simulations conducted for training. This apparent contradiction is not necessarily a real contradiction in simulations conducted for training, in which changing the behavior of the trainees under certain conditions is the objective, or if semiautomated forces (rather than CGF) are used.

FIDELITY, FOG, and FRICTION

Computerized combat models are often received with skepticism—how can a computer program possibly capture such a complex activity as combat? The quality of SIMNET’s synthetic environment, like that of a stereo, is judged in terms of fidelity. Music lovers sometimes have an opportunity to compare the output of their stereos to the real thing (as they recall it) just by listening, and a stereo manufacturer or broadcast or recording engineer can assess fidelity by measuring the sound content of real music and of his product’s output. SIMNET designers were under no illusion that they could fool trainees into actually believing they were in tanks in battle, and they recognized the need to put their efforts where they would do the most good. Thus they decided to measure their success in terms of the degree to which the trainees’ behavior resembled that of actual tank crews, and to adopt a *selective fidelity* approach in which only the details that proved to be important in shaping behavior would be replicated. Cost considerations received their due, and thus the inside of the SIMNET tank simulator could well be termed a minimalist representation of a tank’s interior, while the sounds presented by SIMNET are quite realistic: sound effects are cheap, and people react strongly to them. Especially evocative of reality are the low-frequency ‘‘sounds’’ delivered directly to the seat of the driver’s pants: these verge on being tactile stimuli rather than sounds, and convincingly recreate the sense of driving over uneven terrain.

Users of SIMNET and other *virtual reality* systems almost universally report an initial dismay at the apparent lack of fidelity, followed by acceptance and a report that ‘‘it seemed so real’’ when they start to interact with the program and get a sense of involvement.[35] This feeling can be replicated at any video game arcade.

One can easily carp at particular gaps in realism, and any such observations should be preceded by consideration of the selective fidelity concept and the definition of fidelity as percentage of behavior learned. For example, the German use of cars dressed up as tanks in their prewar maneuvers was a shortcoming in realism but did not stop the German tank crews from deriving considerable training benefit and the German commanders

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[35] SIMNET workers feel that the ultimate accolade, sometimes given after a live field exercise, is a soldier’s statement that ‘‘That felt just like in the simulator!’’

from honing their Blitzkrieg theory of warfare (17).

Yet the gaps in fidelity are there. Even the National Training Center, which affords the trainees real tanks, real terrain, real weather, and human opponents, has been criticized on the basis of residual artificialities such as the inability of its laser ‘‘bullets’’ to penetrate smoke and dust. Such criticisms of NTC, SIMNET, or other high-tech simulations often evoke the response that the low-tech alternatives, such as shooting at white paper targets, are even less realistic. Some skeptics reject even this argument, maintaining in effect that ‘‘a little fidelity is a dangerous thing’’ and that the convincing realism of high-tech simulation could or does perniciously foster negative learning in which the trainees adapt to the simulation, artificialities and all, to the detriment of actual field performance (see box 7).

Accuracy and fidelity must be considered in context. SIMNET's sketchy presentation of the interior of the tank is accepted because the purpose of SIMNET is not to familiarize tank crews with the interiors of their tanks, but to give them experience in using a tank that they already know how to drive. Indeed, for some purposes one could validly dispense with all the high-tech equipment and revert to model tanks on a sand table. An American unit commander in Desert Storm did just that to coordinate the movement of his vehicles and avoid a traffic jam.

Use of SIMNET to create large simulated battles could decrease fidelity by departing from what SIMNET does best—intense armored combat at the company or battalion level. The larger battlefield requires that the soldier perform many other tasks, such as repair and maintenance of his equipment and of himself (including sleeping), ensuring the security of rear areas, and just plain living outdoors. SIMNET does not allow for the simulation of these tasks.

If the goal is to provide higher echelon officers with training and exercise of their command functions, use of SIMNET is not necessary: a CPX, with combat resolution provided by some other means, would afford a realistic training environment for the officers. If, on the other hand, the goal is to fight large battles in SIMNET to find out how large battles work (a laudable goal—for all the effort expended by humanity on war, land battles remain poorly understood) or to experiment with new formations, equipment, or force structure, then SIMNET or something of its ilk may be the right tool, if one can be sure that results are accurate.

Clausewitz cited the great difficulty of obtaining correct information on the battlefield and dubbed it ‘‘the fog of war’’ (16).[36] Traditional combat models have often been faulted for being idealized to the point of omitting the fog of war. SIMNET and other DIS, through their use of multiple people and portrayal of some communications processes, promise to replicate the fog of war better than have previous models. In one SIMNET run witnessed by OTA observers, three M1 Abrams tanks covered the retreat of four M-2 Bradley fighting vehicles that had been deployed far forward as scouts. The four Bradleys safely reached the main U.S. position, a ridge line occupied by hull-down friendly vehicles. The returning M1s were not so lucky: one was destroyed by enemy fire, one was mistaken for an advancing enemy and became an instance of fratricide, and the third became disoriented and lined up on the wrong side of the ridge. Ordered to proceed to the rear, it turned around and proceeded forward and was promptly demolished by the advancing enemy. A traditional computer model would have been hard pressed to produce such a set of occurrences. However, the use of semiautomated forces threatens to remove the human element and reintroduce unrealistic clarity.

36 Clausewitz's classic work, *Vom Kriege* [*On War*], was first published posthumously by his wife in 1832.

BOX 7: Negative Learning Transfer

Providing and manipulating the virtual environments of trainees is done to promote the learning of behavior that will be useful on the battlefield and to promote the retention and transfer of those skills to the real battlefield. However, the effectiveness of the training is limited by the understanding of the designers of the virtual environment. Error or inadequate fidelity can cause negative learning transfer: the learning, in simulation, of behavior that is rewarded with success on the simulated battlefield but is inappropriate on a real battlefield. This possibility is of particular concern to designers and users of combat aircraft mission simulators. Split-second timing is critical in some phases of strike missions and defensive counter-air missions. Where the motor skills coordination must be precise, the simulator must be equally precise. [1]

SIMNET designers encountered what they considered a negative learning transfer when they studied a SIMNET predecessor, the Unit Conduct of Fire Trainer. One trainee thought he was greatly improving his gunnery until his trainer kept quiet. Without the external help directing his attention to targets, the gunner's success rate returned to his initial low percentage.[2] In SIMNET, concern has been expressed about negative learning transfer because the hatches in SIMNET tank simulators are "buttoned up, " After bumping their heads a couple of times, commanders might learn not to look out their hatches.

Artificialities in the live simulation conducted at the National Training Center may also cause negative learning. Because weapons' fire is simulated with lasers, smoke and dust not only provide good visual cover, they actually make the participant impervious to bullets in the sense that a hit will not register since the laser beam will not penetrate the obscurants. A training result might be an overreliance on dust and smoke for cover and overconfidence under such conditions.

How serious a problem is negative skill transfer? Opinions vary, but it is generally agreed that the benefits of simulation training and the advantages it provides for combat readiness far outweigh any negative transfer.

Negative learning can even happen in real combat situations. During World War II, the British engaged the Italians in North Africa and learned how to fight the Italians successfully. When the Germans arrived to reinforce the Italians, the British had all the wrong fighting skills.[3] Fighting skills involve a constant learning process, some of it corrective. With technology changes and upgrades to equipment, old skills have to be unlearned and new skills applied. Dealing with corrections to skill sets is a fact of life with or without simulation, Adaptability in combat is, itself, an essential skill. However, the nature of simulation in training is such that small design mistakes can handicap large numbers of people and any potential negative skill transfer is something that requires, therefore, vigilant watching for and correction as part of the verification, validation, and accreditation process.

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[1] Imprecise coordination of computer-generated imagery with simulator base motion (if any) can also cause *simulator sickness,* which is closely related to motion sickness (seasickness, airsickness, etc.).

[2] J. McDonough, interview with L. Voss at Illusion Engineering Inc., Westlake Village, CA, August 1992.

[3] M. Carver, *Dilemmas of the Desert War* (Bloomington, IN: University of Indiana Press, 1986), p. 16.

SOURCE: Office of Technology Assessment, 1995.

Clausewitz separately identified ‘‘friction’’ as a major force on the battlefield. SIMNET can replicate some sources of friction, such as vehicle breakdowns, but many believe the real world of the battlefield to harbor a myriad of misadventures not provided for in SIMNET or other models.

VERIFICATION, VALIDATION, AND ACCREDITATION

Predictions generated by computerized combat models are often received with skepticism—how can a computer program possibly capture such a complex activity as combat? The issue here is the validity of models and simulations and, more fundamentally, the process—*validation*—by which validity is assessed. The Department of Defense defines validation as ‘‘the process of determining the degree to which a model or simulation is an accurate representation of the real world from the perspective of the intended uses of the model or simulation’’ (153,155,185).

A variety of techniques have been proposed and used to validate computer models of combat; they include critical analysis of the data and computational procedures used in the models and comparison of the outputs (predictions) of models and simulations to actual outcomes—of historical battles (e.g., see references 34 and 15) or exercises (e.g., see references 41 and 141)—or to the predictions of other models and simulations.

Critical analysis of data for correctness is an element of data verification, validation, and certification (VV&C). Critical analysis of the computational procedures used in models is called *structural validation*, which ‘‘includes examination of [model and simulation] assumptions and review of the [model and simulation] architecture and algorithms in the context of the intended use’’ (174). Comparison of model and simulation outputs to outcomes of historical battles is one type of *output validation*, which “answers questions on how well the M&S results compare with the perceived real world’’ (174).

Two related steps in the acceptance process are often considered along with validation: *verification* and *accreditation*. DoD defines *verification* as ‘‘the process of determining that a model or simulation implementation accurately represents the developer’s conceptual description and specifications’’ (185). It establishes that the computer code is free of technical ‘‘bugs’’ (i.e., errors[37]). DoD defines *accreditation* as ‘‘an official determination that a model or simulation is acceptable for a specific purpose’’ (185).

To date, validation of SIMNET has rested largely on users’ assertions that it ‘‘feels right.’’ Such declarations are evidence of *face validity*—i.e., that on the face of it the experience is not so unrealistic as to preclude the intended use. However, such declarations do not guarantee that the effectiveness of the vehicle, crew, or unit will be in combat what it was in simulation. In fact, some observers worry that SIMNET may feel too right—that it may be ‘‘seductive’’ (32).

For example, a tank commander must discern an enemy tank at a distance of a thousand yards or more, despite the camouflaged appearance of the enemy and his likely exploitation of concealment offered by vegetation or terrain. This task pushes human vision to its limits. Although target acquisition feels the same in SIMNET as in real life (each requiring great alertness and a quick reaction to the first sign of the barely-detectable enemy), real-life target acquisition entails the interpretation of visual details far too subtle to be presented on a SIMNET screen, creating a discrepancy in the average distance at which targets are acquired. Such a discrepancy can be discovered only through a systematic validation effort, such as one that was undertaken to validate target acquisition models (205). Other discrepancies, such as the tank commander’s limited field of view in an M1 simulator, are more obvious and are

[37] Reference number (78) describes the origin of this use of the word ‘‘bug.’’

FIGURE 6: Close Combat Tactical Trainer Simulator—Artist's Conception

This illustration depicts a virtual battlefield scene such as might be displayed in a Close Combat Tactical Trainer simulator--except the armored vehicles and aircraft are cut away to show cut-away views of the simulators in which crews are controlling the operation of their simulated vehicles on the virtual battlefield. Also depicted is the cabling that connects the simulators. The vehicles shown include Abrams tanks (foreground and center), a Bradley armored fighting vehicle (left, with infantry troops dismounting), an Apache helicopter (above left), a U.S. Air Force A-10 Warthog close air support aircraft (above left center and above right), dismounted infantry troops (center, beyond Abrams tank), and various enemy vehicles (above right). Close Combat Tactical Trainer simulators have not yet been built.

SOURCE: U.S. Army, Combined Arms Tactical Trainer Project Manager, 1995.

being addressed in the Army's Close Combat Tactical Trainer (CCTT) project—the follow-on to SIMNET-T (see figure 6).

Various approaches to validating SIMNET through comparison of its results to presumed facts[38] can be imagined. One validation project conducted by DARPA collected detailed data about the Battle of 73 Easting (a tank battle in the Persian Gulf War). DARPA compared the data to the results of SIMNET simulations to see how closely the simulated battles compared to the real one (15). Similar comparisons have been performed with constructive models such as CASTFOREM (50), the Concepts Evaluation Model

[38] It is sometimes difficult to identify the real world to which a model's or simulation's output should be compared: "The basic point about 'reality' is the non-existence of general agreement as to what it is.. . . As in science generally, the dichotomy of' fact' and 'theory' is an oversimplification" (140). See also reference number (174).

(204), Janus(A) (107, 109), the Oak Ridge Spreadsheet Battle Model (56), various Lanchestrian models (34,52,53,54,58,108), the Quantified Judgement Model (30), and other models (94), applied to battles too numerous to list here exhaustively[39] but including the Battle of Iwo Jima (34), the Battle of the Bulge (Ardennes 1944) (204), the Inchon-Seoul Campaign (52), the Six-Day War of 1967 (30), the 1973 War of Atonement (30), the 1982 War of the Cherry Blossoms in the Bekaa Valley of Lebanon (30), the Battle of 73 Easting in the Persian Gulf War (50,107), and the World War II U-boat campaign in the Bay of Biscay. In current DoD terminolgy, these comparisons would be described as output-validation activities intended to validate (or to invalidate) the models for predictive uses by comparing their predictions to historical outcomes.

This approach to validation is not quite as easy at it sounds. One problem is obtaining good data for such an undertaking; this may be impossible (e.g., if one is interested in validating a model of strategic nuclear war between superpowers) or could require more time and money than did creating the model in the first place. Those who attempt it may be subjected to the unenlightened charge that it is waste of money to predict the past. Another possible pitfall is that if modelers use all applicable historical cases to create the model (56), comparing its predictions to those outcomes may show what looks like a good fit to the layman, but it would have no *goodness of fit* in a statistical (i.e., scientific) sense, and the model's *predictions* would be of uncertain accuracy and reliability. A statement such as ''we have calibrated our model to the results of the 1973 Arab-Israeli war, and it can reproduce them perfectly'' (62, p. 145) implies that the model has *descriptive validity*—i.e., it explains the outcome of the combat (22)—but the statement provides no confidence in the reliability with which the model will predict the outcome of a similar future war, and other models may be able to be calibrated to explain the outcome equally well.

It should also be recognized that the historical outcome may have been a freak occurrence. For example, naval warfare modelers would be hard-pressed to reproduce the defeat of the *Bismarck*, which entailed a lucky torpedo hit on the ship's rudder. Some have argued that the Battle of 73 Easting had many unique features that make it unrepresentative of likely future battles. Even if it were perfectly representative, it is only one case, and if other conflicts began the same way, they might not end the same way. The late military historian Trevor DuPuy said in 1991 that:

> I would be most reluctant to take 73 Easting as the truth of history. It is true, but it is not necessarily consistent with the best truth. We must have many, many more before we can say what the lessons are that have been learned from this (32).

A related approach would be to load SIMNET with a battle fought at the NTC and see whether the SIMNET results match NTC results. The events of the Battle of Seventy-Three Easting, while extraordinarily well-documented, are far from perfectly known. For example, it is not known whether the crews of some or all of the Iraqi tanks were hiding in bunkers near their vehicles when the U.S. forces opened fire and could not return fire immediately. It is also not known whether some of the Iraqi tanks had been destroyed by U.S. bombing before the battle. Finally, the outcome of 73 Easting may have been one of several possible outcomes. Use of NTC battles for validation would be preferable, at least in this regard, because the validators could pick an NTC battle that has been fought many times and for which there is a resulting strong sense of how it usually turns out and of the variation in outcomes.

On the other hand, use of NTC battles to validate SIMNET for predictive uses would beg the

[39] See references (30) and (56) for other examples.

question of whether NTC exercises are themselves valid live simulations. There are doubts:

> I'm always concerned about NTC data, because it isn't real war, despite the stress and strains and drama of the exercise. People know that they'll be going home that evening and getting a warm, good meal and sleeping in a relatively warm bed (32).

More fundamentally, model-to-model and simulation-to-simulation comparisons are often dismissed with the argument that two simulations could agree, and both could be wrong. However, such comparisons are useful, because if it turns out that two simulations disagree in an important respect, then they cannot both be valid,[40] and discovering this can be important. Moreover, if one of the simulations was previously validated and accredited, it could be used as a proxy for reality, for purposes of output validation.

Another, and very different, approach to validating SIMNET (or any similar system) would entail detailed examination of its inner workings. The obvious starting point for this structural validation is the set of assumptions embodied by the model. Some assumptions are data. Some engineering data, such as armor thicknesses and vehicle road speeds, are so well known as to be unlikely to pose any problem, but closely related performance parameters, such as armor penetration and vehicle speeds over various types of sand and soil, may be based on test-range trials whose conditions may or may not make them suitable for use.[41] Assumptions that are not engineering data, or perhaps not data at all, are harder to validate. False assumptions are not the only threat: *missing* assumptions are much harder to detect and their consequences are often much more severe. One can satisfy oneself that all of a model's assumptions are true and still have room for concern that the model's output might be untrue.

Having examined the model's data, a structural validation effort would continue by examining the equations and other relationships that make the model function as it does. Some of these, such as those governing the flight of projectiles, would be straightforward and incontestable physics or engineering equations. Others, such as those relating fires to smoke and smoke to obscuration, could prove at least as contentious as the data used to drive them.

In the case of simulations such as SIMNET that present a person with sensory input, a final step in validity checking is needed: that which establishes that the sights and sounds presented to the trainee are as they should be. If some submodel determines that a given burning tank should create smoke that restricts visibility to 20 meters, does the model's synthetic environment in fact present objects out to 20 meters and no farther when the user drives into the smoke from this burning tank?

It would at first appear that virtual simulation could not induce the perception of being in mortal danger. If this were true, it might add an irresolvable obstacle to the assessment of validity of virtual simulation, which is not to say that it would make inaccurate predictions. However, in some cases it may be possible to measure the physiological stress of simulator users and compare it to the stress of actual combatants. There are clinical precedents: in two recent experiments acrophobic patients were transported virtually (by means of a head-mounted display) to a high place in a synthetic environment and their physiological signs of stress were measured (63,82,134). The stress was presumably a symptom of fear (phobia). However, the only way to assess the fearfulness, per se, of a subject is to ask the subject whether he or she is fearful, as S.L.A. Marshall did for *Men Against Fire* (91).

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[40] Possibly the simulations consisted of using models to generate predictions based on erroneous, invalid data. In this sentence, we use simulation in a broad sense, to include data.

[41] More likely, and much more threatening to validity, the performance parameters are as much the results of running other models as they are of testing equipment in the field. For a detailed and seminal treatment of this problem, see (135).

The same could be done with users of simulators of real or proposed weapon systems. The difficult (but not impossible) step in such a comparison would be making corresponding measurements on and assessments of actual combatants. Some—perhaps most—people would consider this a waste, believing it obvous that real combat is more stressful and fear evoking than simulated combat, for most soldiers. Cases of simulator users losing the insight that ''it's not real'' are so rare and startling—even amusing—that they are recounted as anecdotes, even in Congess, by proponents of virtual simulation.[42] However, even if simulators do not (or are not allowed to) evoke the same stress and fear that combat does, the effect on a virtual simulation's predictive accuracy and reliability is unclear, because some individuals perform better when stressed and fearful, while others perform worse. Unit leaders endeavor to channel their soldiers' responses to fear into constructive action rather than panic.

Another way in which simulator operators may behave unlike real combatants is that they may participate in the same scenario so many times that they learn. This is desirable for training but is usually undesirable in research, in which the objective is often to predict how effectively human operators will behave the first time they see real combat. Accruing statistical confidence in such predictions requires many repetitions (11,41, 141), but preventing the operators from learning might require using a fresh crew for each repetition. An alternative approach that has been used in the validation of a small-unit entity-level constructive simulation (41,141) is randomization of scenarios, to estimate and account for learning.[43]

The degree to which a model's output should be believed also depends in part on what the output is. Models are to a considerable degree idealizations, and as such generally understate the deleterious effects of the fog of war, and portray military activity as proceeding more smoothly than it really does. Similarly, even if a virtual prototype works well in simulation, a physical system built from the design may fail because of some detail or phenomenon that was not modeled. On the other hand, if a virtual prototype functions poorly, it seems doubtful that unmodeled phenomena would make it work better in the real world.

Accreditation constitutes official certification that a computer model is acceptable for a particular purpose. It provides assurance to users, particularly contractors, that their work will not later be dismissed on the grounds that it was performed using a questionable computer model. It has been suggested that accreditation for a particular purpose be extended not simply to models but to model-user combinations (21).

A problem underlying much of the difficulty of creating valid military simulation models is the lack of necessary data, and in general the lack in the U.S. system of what is termed *military science* abroad (20). There is no consensus as to how one validates a model and what constitutes a valid reality against which to check it, though there is no shortage of practical biases and philosophies about what standards modeling and simulation

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[42] Dave Evans of Evans and Sutherland, a pioneer in computer image generation for cockpit simulators as well as head-mounted displays (HMDs), has said that one pilot flying a Boeing 747 airplane simulator fainted when his virtual airplane hit a ditch on landing. Professor Frederick Brooks, quoting him, said that nothing so dramatic had happened to a trainee wearing an HMD (10).

[43] For example, if a simulation experiment were conducted to assess whether tank units would be more effective, in a certain scenario, if their tanks were equipped with a new radio system, the crews of 10 units might participate in 10 exercises each—5 exercises using the simulated inventory radios and 5 exercises using the simulated proposed radios. The order in which each unit uses inventory radios and proposed radios should be chosen randomly, so that, for example, crews do not all use the inventory radios 5 times while warming up and then the proposed radios 5 times after having improved their proficiency—an improvement that careless analysis might attribute solely to advantages of the proposed radios. More sophisticated experiments and analysis could estimate the rate of learning and extrapolate performance with each radio back to estimate cold (i.e., unrehearsed) performance with each radio or forward to estimate performance with each radio after much practice and rehearsal.

should meet. Lack of standards for models inhibits their verification and use. A program manager trying to select an appropriate model to use to support his program ‘‘finds it very difficult to locate unbiased help in deciding what model to choose, what data [are] acceptable, and what models have been successful in the past. Each program manager is, to a great extent, left on his own to make these decisions and then defend them against a host of organizations which are chartered to challenge such decisions’’ (101, p. 36). Models tend to be biased toward fulfilling the needs of a particular military service or defense agency. They will represent with high fidelity the details of interest to a particular service but not those of interest to other services. Different communities have contradictory requirements for models. Models developed by the acquisitions community, for example, are traditionally not accepted by test and evaluation agencies. Current practice for test and evaluation personnel is to assume that acquisition models, which are developed by the contractors of the system, are inherently biased (101, p. 2). In the training community, the validity of SIMNET exercises is questioned, since they do not meet traditional training measures (201, pp. 14-15).

One interesting contrast between the field of defense modeling and other similar fields, e.g. econometrics,[44] is the lack of a tradition of validating models routinely (21, p. 30). Peer review would seem to present an ideal solution to the difficulties posed by the field of defense modeling, but peer-reviewed journals cater to an academic side of the field that is more that usually detached from the real-world version. (This split is doubtless exacerbated by security considerations.) Articles appearing in these journals often have a more judgmental character than articles in scientific journals. The field of defense modeling combines empirical, historical, mathematical, and judgment in a mix likely to sow disesteem among peers: the more subjective aspects create plenty of room for disagreement, while the ability to point to a few facts allows the disputants to feel that their opponents are not dealing with reality.

It is in this context, then, that one must consider short-term proposals to accomplish validation in part, or entirely, by peer review of the work or by the certification or licensing of the workers. Workers fear that such review, certification, or licensing by peers would at best institutionalize back-stabbing and at worst foster the creation and self-perpetuation of a one-viewpoint orthodoxy.

In the long run, peer review could perhaps be made to work if a healthier combat modeling culture develops. At present such a culture is hard to identify because of the security classification surrounding a considerable portion of the work, the disparate backgrounds of workers in the field, the near-total lack of a full-fledged academic curriculum related to combat modeling,[45] and the distaste with which some view the organized study of how to kill people in large numbers. These barriers seem difficult to surmount, and lead to the discussion of standards in the following section. It is important to note, however, that one form of peer review exists at present and appears to work—internal peer review. Through a conscientious program of internal peer review, some organizations devoted to defense modeling and simulation do manage, according to their own view, to enhance the quality of their products.

A number of recent efforts to improve validation of M&S, including some used for DIS, are noted in the following subsections.

[44] Even in econometrics, the fitting of a model to data is more common than is the statistical testing of the resulting model on the basis of subsequent data, accounting for degrees of freedom (i.e., the number of ways in which the model can be made consistent with the peculiarities of the data to which it was fit, rather than to basic trends in the data). Complex models developed by academic economists are seldom validated (83,84).

[45] OTA recognizes that several first-rate universities offer courses of study and research in defense policy analysis, but these programs are small and cast a wide net. They often combine political science and defense modeling in a single course.

Army Pamphlet 5-11

The Army's pamphlet, *Verification, Validation, and Accreditation of Army Models and Simulations*, issued in 1993, (174) is the most detailed official plan for VV&A yet released by a DoD component. More recently, the Marine Corps issued a VV&A plan, and the other services, and DoD, have drafted plans.

SEES 2.0 Accreditation Exercises

From 1993 (41) through 1995 (141) Lawrence Livermore National Laboratory's Conflict Simulation Laboratory (LLNL CSL) has documented a series of force-on-force (FOF) exercises (live simulations). They were conducted in October 1992 at the Wurtsmith Air Force Base Weapon Storage Area to "accredit" (as well as validate) the Security Exercise Evaluation System version 2.0 (SEES 2.0). SEES 2.0 is a multiuser, interactive, entity-level constructive simulation, that can simulate the behavior of individuals in small units such as infantry squads, security police patrols, special forces units, or terrorist groups, under the supervision of squad or team leaders. Although SEES 2.0 is neither a DIS or a virtual simulation, the method used by CSL to inform accreditation could be used to validate distributed interactive virtual simulations. We briefly summarize the SEES accredition study here.

The LLNL CSL developed SEES 2.0 for the Air Force Security Police and the Defense Nuclear Agency for use in evaluating the physical security of weapon storage areas and other facilities. It was developed from the Urban Combat Computer Assisted Training System and later evolved into the Joint Tactical Simulator.

The accreditation study defined two quantitative measures of performance that were predicted by the SEES, relevant to the application, and measurable in live simulations. One measure was the friendly-to-hostile force ratio, which varied as the live or constructive simulation progressed. The other measure was the time (after the beginning of the simulation) at which key events occurred, such as the transport of a stolen weapon through the weapon storage area security perimeter. For each of several conditions (*scenarios*), several attacks were simulated. In the terminology of experimental design, this provided for blocking and replication.

SEES 2.0 is a stochastic, *Monte Carlo* simulation. In different SEES simulations (as in live simulations) starting from the same condition, different things happen in general and to the measures of performance in particular. Several SEES simulations and several live simulations were conducted for each scenario, to increase the statistical confidence with which one could conclude that SEES was a valid model of the force-on-force exercises, or to reduce (i.e., improve) the statistical significance with which one could conclude that performance measures of SEES simulations were statistically different from those of the FOF exercises. The SEES and FOF results were compared using a two-sample Kolmogorov-Smirnov test. (See box 8.) At most times during the scenario, one could not distinguish the SEES force ratios from the FOF force ratios with less than a 10-percent chance of error. However, there was one time at which the SEES force ratios could be distinguished from the FOF force ratios with less than a 10-percent chance of error, implying that SEES did not accurately predict what the live forces did at that time in the live simulation. Analysis of simulation data indicated that SEES predicted implausible individual and unit behavior in a certain ambush situation. This conclusion led to subsequent adjustment (*tuning*) of the SEES model.

The accreditation study report acknowledged that several issues of validity could be raised: one is whether the live forces, who 1) used MILES equipment instead of actual weapons, 2) were obliged to observe Occupational Health and Safety Administration regulations, and, 3) because of instrumentation limitations, were required to operate in daylight (contrary to doctrine and training) in most replications, could be considered proxies for real forces operating under operational conditions. The scaling of scenario time to compare the pace of action in the live exercises with the faster pace in SEES runs, and the use of

BOX 8: Use of the Two-Sample Kolmogorov-Smirnov Test in Validation

The two-sample Kolmogorov-Smirnov (K-S) test[1] is a statistical procedure that can be used to decide whether two sets of data (for example, one set from a constructive simulation, the other from a live simulation or from history) are statistically equivalent,

Specifically, the two-sample K-S test is a statistical procedure for deciding whether two groups (samples) of numbers, each selected randomly (and independently, with replacement) from a larger group (a population) of numbers, were selected from the same population or, alternatively, from different populations.

For example, in one of the K-S tests performed in the SEES V2.0 accreditation project, one sample (called the simulation sample) was a set of 40 Red/Blue (i.e., hostile-to-friendly) surviving force ratios at two minutes after the commencement of hostilities, from 40 simulations of a scenario (called Scenario 3) using SEES V2.0, a constructive simulation with human participation. The other sample (called the experimental sample) was a set of 20 Red/Blue surviving force ratios at two minutes after the commencement of hostilities, from 20 force-on-force (FOF) exercises with the same scenario. On the basis of a two-sample K-S test, the authors of the project's final report[2] concluded, with a statistical significance of about 0.0281, that the two samples of force ratios were drawn from different populations—i.e., that the surviving force ratios predicted by SEES V2.0 were not the same, statistically, as the surviving force ratios from the live simulation, The phrase "with a statistical significance of about 0.0281" means "with a probability of error no greater than about 0,0281" (i.e., about 3 percent). It was later determined[3] that this discrepancy arose in part because of "the inadequate modeling in SEES of human factors for ambush situations. "[2]

The qualification, ". . . about ., .," refers, in part, to the fact that the authors used an approximate version of the K-S test that is accurate for comparing very large samples (i. e., samples containing data from many replications of a simulation or experiment) but is not necessarily accurate for comparing samples of 20 or 40 numbers. An assessment of the accuracy for the sample sizes used in the accreditation project was planned but was never conducted because of resource limitations.

OTA also uses the qualification, "... about.., " to refer to uncertainties introduced by other practices. For example, as noted above, the K-S test may only be properly applied to samples selected

the asymptotic (large-sample size) version of the Kolmogorov-Smirnov test for the comparisons were also flagged for discussion.

A2ATD Validation Experiments

In 1994 the Army conducted the first of six experiments planned to validate BDS-D simulators, SAF (called SAFOR), and the BDS-D simulation (simulators and SAF operating together). The VV&A effort is funded by the Army's BDS-D program and is conducted as part of the Army- and ARPA-funded Anti-Armor Advanced Technology Development program. The VV&A effort is intended to address a deficiency of particular interest to Congress: "The current BDS-D simulation capabilities are not adequate for evaluations to support acquisition decisions. . . A2ATD. . . was initiated with the goal of maturing DIS as a credible evaluation tool to support acquisition decisions" (11). Box 9 describes the A2ATD in greater detail.

Joint Staff Instruction on VV&A

On January 12,1995, the Vice Director of the Joint Staff issued Joint Staff Instruction 8104.01, *Verification, Validation, and Accreditation of Joint Models and Simulations* (183). Modeled on Army Pamphlet 5-11, it specifies general VV&A procedures for use by the Joint Staff.

BOX 8: Use of the Two-Sample Kolmogorov-Smirnov Test in Validation (Cont'd.)

randomly and independently, with replacement, from a population. In the case of the simulation sample or the experimental sample, the *population* refers to all the force ratios that would occur if the exercise were repeated an infinite number of times, in each case under the same conditions (including participant experience). Random and independent selection, with replacement, implies that each possible force ratio should have the same probability of occurring regardless of the replication number—e.g., it should have the same probability of occurring in the first, second, and twentieth replication. This implies that there should be no learning by Red or Blue forces, over the course of those successive simulations, in any way that would have an influence on the probabilities of force ratios at two minutes after the commencement of hostilities. In order "to reduce [the] learning curve" in the force-on-force exercises, the SEES accreditation project allowed the Red and Blue forces 38 "free plays, " in addition to the 40 "record events"[3] (20 for each of 2 scenarios), in the force-on-force exercises. Free play was also allowed in the later SEES V2.0 simulations. In spite of this, the SEES participants, "without coaching, learned the same successful tactics as [did the] FOF [exercise] participants. "[3]

The experimental and simulation samples for other times after the commencement of hostilities (at least until eight minutes) were in better agreement. For times at 30-second intervals from the start until seven minutes later (except for two minutes after start), the experimental and simulation samples were not so different statistically that the K-S test could reject the hypothesis that they were drawn from the same population with a statistical significance better (i.e., less) than 0.10. In fact, at 4.5 minutes after the commencement of hostilities the experimental and simulation samples were so similar that the hypothesis that they were drawn from the same population could not be rejected with statistical significance better than 0.9853,

[1] D.A. Darling, "The Kolmogorov-Smirnov, Cramer-von Mises Tests, " *Annals of Mathematical Statistics,* 28:823-838, 1957.

[2] G. Friedman and R. Toms, *Security Exercise Evacuation System (SEES) V2.0, Accreditation Project Final Report,* February 1993, FOR OFFICIAL USE ONLY,

[3] R.M. Toms, "Results of a Verification, Validation, and Accreditation Excercise," briefing, presented at the Office of Technology Assessment Workshop on Issues in Combat Model Validation, Washington, DC, Feb. 8, 1995.

SOURCE: Office of Technology Assessent, 1995,

TRADOC Research on DIS Validation

The Army's Training and Doctrine Command (TRADOC) has been sponsoring conceptual work on DIS validation. One study, by the RAND Corporation, which was to consider alternative approaches to the problem, is nearly complete (26). It elaborates ideas expressed in earlier RAND work on validation (21,22,64), focusing on DIS and emphasizing that there are a number of nonpredictive uses of DIS for which comparison of model predictions—or DIS outcomes, construed as predictions—to historical or future real-world outcomes is neither necessary nor appropriate for validation. For example, if a system of DIS equipment, software, and databases is to be used for training, then validation should seek to assess the degree to which trainees have learned the desired conditional behaviors as a result of the training.[46]

Predictive uses are classified into various subcategories of weakly predictive uses and strongly predictive uses, the former denoting predictions with considerable uncertainty, such as theater combat simulations, and the latter denoting pre-

[46] This begs the question: why are those conditional behaviors believed to be good or optimal'?

BOX 9: Anti-Armor Advanced Technology Development (A2ATD)

The Anti-Armor Advanced Technology Development (A2ATD) program was undertaken by the Army and DoD as a whole, with the goal of improving DIS applications enough to be credible as an evaluation tool to support acquisition decisions. The purpose of the A2ATD is to develop and demonstrate a verified, validated, and accredited DIS capability to support anti-armor weapon system virtual prototyping, concept formulation, requirements definition, effectiveness evaluation, and mission area analysis on a combined arms battlefield at the battalion task force or brigade level.

The A2ATD program has four technical objectives:

- demonstrate DIS as an evaluation tool and verify, validate, and accredit simulators used in A2ATD experiments, semiautomated forces, and the Battlefield Distributed Simulation-Developmental (BDS-D) simulation;
- develop, demonstrate, and document techniques and analytical tools to evaluate the causes of simulation outcomes;
- link one or more constructive models such as Janus to DIS; and
- demonstrate upgraded virtual prototypes of M1A2 Abrams tanks, M2A3 and M3A3 Bradley armored fighting vehicles, non-line-of-sight (NLOS) and line-of-sight antitank (LOSAT) weapons, and virtual prototypes to be developed—of the Apache and Comanche helicopters, the Enhanced Fiber Optic Guided Missile (EFOGM), AGS, JAVELIN, and Hunter.

In FY 1993 VV&A of simulated and semiautomated forces and development of analytical tools to support the evaluation of causes of simulation outcomes began, with the goal of providing the foundation for a series of six experiments in FY 1994-1996. The first experiment, completed in September 1994, replicated two M1A2 Initial Operational Test and Evaluation (IOT&E) vignettes to compare the results of virtual simulation with those of live simulation and to compare constructive simulation with live and virtual simulation, Four experiments planned for FY 1995 will use BDS-D simulation of the effects of heavy force modernization in a Southwest Asia scenario and demonstrate the linkage of Janus to BDS-D, BDS-D and ModSAF VV&A will be systematically expanded by addition of the following simulators: Apache, Comanche, M1A2, M1A2 firing STAFF, LOSAT, and NLOS. One experiment will be conducted in FY 1996, a Rapid Fire Projection Initiative scenario with AGS, LOSAT, EFOGM, JAVELIN, and Hunter simulators. Experiments 1 ,2, and 4 will be local-area network experiments conducted at the Mounted Warfare Test Bed (MWTB). Experiments 3, 5 and 6 will be wide-area network experiments. Experiment 3 will link the MWTB, Land Warner Test Bed (LWTB), and the BDS-D site at TACOM. Experiment 5 will link the MWTB, LWTB, and the Aviation Test Bed (AVTB). Experiment 6 will link the MWTB, LWTB, and BDS-D site at MICOM.

The A2ATD experiment analysis cycle will proceed as follows. The scenario vignette and performance data will feed into BDS-D and the Combat Arms Task Force Engagement Model (CASTFOREM). BDS-D simulations will be run with verified, validated, and accredited ModSAF and simulators (level 2 CIGs) in a level 2 environment with level 2 DIS standards. BDS-D simulation runs will be made with and

dictions with little uncertainty, such as some engineering simulations. The draft report concludes that use of subjective judgement may be necessary for weakly predictive uses, and it notes the importance of describing and quantifying the uncertainties in the predictions.

MORS SIMVAL ’94 Symposium

In September 1994 the Military Operations Research Society held SIMVAL ’94, the fourth in a series of mini-symposia and workshops designed ty address the problem of simulation validation.

BOX 9: Anti-Armor Advanced Technology Development (A2ATD) (Cont'd.)

without simulators to provide the basis for comparing SAF and simulator behaviors and simulation outcomes. ModSAF behavior algorithms will be changed as appropriate for subsequent experiments. BDS-D simulation outcomes will also be compared to CASTFOREM outcomes to determine difference-sand reasons for differences. CASTFOREM algorithm changes and runs may be made to try to bring the outcomes into better agreement with BDS-D simulation outcomes. CASTFOREM runs will be made for the full scenario with the version of CASTFOREM that produces the best agreement with BDS-D simulation results. Results of the BDS-D simulation and CASTFOREM runs will be analyzed to evaluate anti-armor weapons' contribution to force effectiveness and to provide the basis for BDS-D simulation VV&A.

ModSAF physical algorithms for vulnerability target acquisition, delivery accuracy, mobility, and rate of fire were validated as conforming to Army standards, and system performance was consistent with the M1A2 simulator. Behavioral algorithms were validated as being able to represent armor tactics and doctrine. ModSAF was benchmarked for Experiment 1 against IOT&E and CASTFOREM.

DIS analytical tools were developed to support simulator and ModSAF VV&A and to evaluate causes of simulation outcomes. A quick-look analysis capability was developed to permit review of experiment outcomes within 30 minutes of trial completion. Protocol data units were added and post-processors were developed to analyze the causes of simulation outcomes for the spectrum of measures of effectiveness, performance, and behavior specified in the evaluation plan. Each element of the network was integrated to insure that it could send and receive protocol data units. The network was also exercised to insure that it had sufficient throughput to render real time images for the scenario.

Detailed evaluation and test plans were prepared and troops were trained before the experiment. Pilot tests were run to insure that the experiment could be executed and data could be collected and analyzed using DIS analytical tools. CASTFOREM was run prior to the experiment to fine tune the scenario and benchmark ModSAF.

Forty-eight trials were run over a 12-day period. Twenty-four trials were run for each vignette (12 trials with manned simulators and 12 trials with ModSAF only). The two vignettes run were a hasty attack (14 M1A2 tanks attacking 4 tanks and 3 BMPs[1]) and a hasty defense (14 M1A2 tanks defending against 26 tanks and 1 BMP). Four M1A2 simulators were used in the manned simulator trials. To minimize crew learning effects the scenario and platoon location were randomized.

The first A2ATD Experiment developed and demonstrated the first integrated DIS capability using 2.0.3+ protocols, high-fidelity environment, next-generation image generators, validated simulators and ModSAF, and DIS analytical tools to support VV&A and analysis of experiment outcomes. As a by-product of the first experiment, the MWTB was modernized and W&A tools and procedures are being offered as DIS VV&A guidelines.

[1] A BMP IS a type of armored vehicle originally produced in the Union of Soviet Socialist Republics

SOURCE: W.J. Brooks, "Anti-Armor Advanced Technology Demonstration (A2ATD)," *Phalanx,* December 1994; available online at <URL:gopher//triton.dmso.mil.:70/11/twg/mors/phalanx/a2atd.txt>

The objective of SIMAL '94 was to address the question: "How much validation is enough?" The group agreed that "there were no quantifiable units for V&V" (207). The implication is that the MORS group could not find a way to determine how much validation there is, or how much is enough.[47]

Afterwards, the SIMVAL Senior Advisory Group met and decided to use the output of the workshop to draft a set of VV&A templates. The draft guidelines will be posted on an electronic bulletin board system for review, comment, and revision. When it appears that a consensus has been reached, the revised guidelines will be published. No additional SIMVAL workshops will be planned until the M&S community has had a chance to use the draft guidelines in case studies (207).

DoD Modeling and Simulation Master Plan

In January 1995 the Under Secretary of Defense for Acquisition and Technology began formal coordination of the Final Draft of the *DoD Modeling and Simulation Master Plan* (195). A complex and important document, it lays out a vision, goals, and responsibilities for VV&A and other tasks required (153) for management of Defense models and simulations. Specifically, it requires a DoD Instruction on VV&A to be prepared—and one has been drafted (154). It echoes the question, ‘‘How much validation is enough?’’ as an unresolved issue.

Methodology Handbook for VV&A of DIS

DMSO has sponsored the drafting of a methodology handbook for VV&A of DIS (175). It is aimed at DIS exercise managers. A companion document, the *DIS VV&A Implementation Guide*, is being developed to describe in detail the actions required to accomplish each step identified in this VV&A handbook. If done well, the *DIS VV&A Implementation Guide* could serve as the much needed key to quantifying validation so the requirements could specify how much is enough.

OTA Workshop on Validation

OTA hosted a workshop on issues of validating combat models on February 8, 1995. OTA's purpose was to hear views and collect information for possible inclusion in the report of this assessment. Some of the material presented is summarized in this background paper—e.g., in the section “SEES 2.0 Accreditation Exercises” above and in the following section.

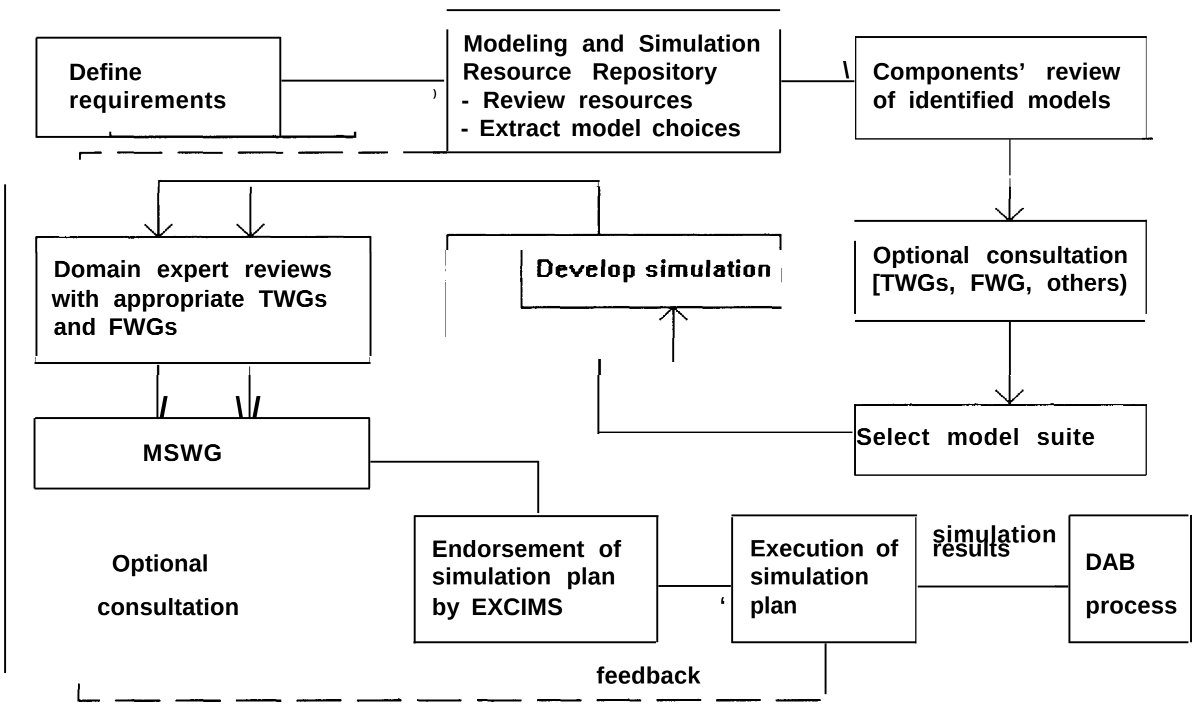
Validation of CCTT for Training

The Project Manager (PM CATT) of the Army's Combined Arms Tactical Trainer project (CATT) has been conducting a vigorous effort to validate the Close Combat Tactical Trainer (CCTT), which is the first of several DIS-based training systems to be developed under the CATT funding and management umbrella. PM CATT recognizes that because CCTT is to be used for training, CCTT validation should seek to assess the degree to which trainees learn desired conditional behaviors (i.e., different behaviors in various situations) as a result of CCTT training. Documenting the behaviors desired in various tactical situations has been a major effort, involving detailed research into hundreds of Army training manuals, field manuals on doctrine, and other documents. However, this process is a necessary step in the measurement of the effectiveness of training and of training transfer—i.e., the transfer of behaviors learned in a simulator to a real vehicle.

OTA notes that validation of CCTT (or any other program) for particular training uses does not validate it for predictive uses, such as predicting the force multiplication that some proposed command and control system would provide to a tank battalion under specified circumstances. Such a

[NO TAG] OTA partly disagrees: the SEES accreditation study illustrates how specific measures of performance can be defined and how statistical tests can determine the statistical significance at which one cannot distinguish simulation outputs from actual outcomes in history, future history, or some set of live simulations considered to be a proxy for future history. Of course, details of implementing such a comparison will vary from case to case, and how little statistical significance to require (‘‘how much validation is enough?’’) remains a subjective matter, generally implying a value judgment.

FIGURE 7: Simulation Endorsement Process Proposed for Acquisition Applications



SOURCE: DoD Executive Council for Modeling and Simulation

use would be a misappropriation (4) of CCTT models and simulations, unless they are validated for the predictive use.

Cost/Training Effectiveness Analysis

A recent report by DoD's Office of the Under Secretary of Defense for Personnel and Readiness noted that an early evaluation of CCTT "Quickstart" modules will be the first major DoD study to quantify the training benefits of advanced distributed simulation (192). A project to improve Cost/Training Effectiveness Analysis is now in progress (in Phase 2) at the University of Central Florida's Institute for Simulation and Training; it is sponsored by the Office of the Assistant Secretary of Defense (Force Management and Personnel).

Simulation Endorsement Process

At the March 22, 1995, meeting of DoD's Executive Council for Modeling and Simulation (EXCIMS), Captain James Hollenbach, USN, Director of DMSO, briefed the EXCIMS on a proposed simulation endorsement process that would involve the EXCIMS in the joint acquisition process as a simulation endorsing agency. Following discussion, the EXCIMS agreed to test the process in the context of the Joint Advanced Strike Technology (JAST) Program, which volunteered to test the process. Based on the results of this test, the EXCIMS will decide whether it will serve as a simulation endorsing agency (180). The process (see figure 7 (67)) is, in essence, a process that the EXCIMS could use to assure itself, and to try to assure the Defense Acquisition Board (DAB), that

BOX 10: Protocol Data Units (PDUs)

The DIS protocol specifies types and formats of Protocol Data Units (PDU)s, which are packets (physically speaking) or *datagrams* (logically speaking) of simulation data transmitted from one simulator to any or all other simulators in a distributed simulation. Various kinds of computers and simulators can communicate simulation data to one another by using standard PDUs Most PDUs defined by the current DIS protocol standard are variations of the User Defined Protocol (UDP) datagrams used by some computers on the Internet.

The DIS protocol standard and a companion document, commonly known as the DIS enumeration documental specify the sequence in which various bits of information are transmitted in each type of PDU.

Changes in the PDUs[2] are enabling new kinds of information to be passed. The demonstration of the 2.0 version of the DIS protocol, for example, included electromagnetic transmissions data, which enables the simulation of radio communication. A protocol that includes what is known strategically and tactically—intelligence about the enemy, command and control data, what is known about an enemy's location—has been proposed. This would allow simulation exercises to be restarted with the same amount of known information available to both sides.

The table[3] on the next page shows some of the types of PDUs for the current standard, DIS 1.0, and proposed revisions 2.0 and 3.0. The simulation management protocols proposed for DIS 2.0 would allow new entities to be networked without having to add code for modeling them to each simulator. They would also contain information that would capture the state of the simulation, allowing it to be recreated or examined at a later time DIS 3.0 PDUs may possibly contain information for reflecting changes in the terrain, such as when a bomb has created a crater in the road. New PDUs may also provide for additional capabilities for translating between models and simulators with different levels of fidelity, representing unaggregated, aggregated, and disaggregated entities.

[1] The latest version of what is commonly called "the DIS enumeration document" is: Institute for Simulation and Training, *Enumeration and Bit-encoded Values for Use with IEEE 1278.1 Standard for Distributed Interactive Simulation—Application Protocols,* IST-CR-95-05 (Orlando, FL: Institute for Simulation and Training, 1995); available online as <URL:ftp://ftp.sc.ist.ucf.edu/public/STDS/enum/enum95.doc>

[2] U S. Army, Simulation, Training, and Instrumentation Command, "Distributed Interactive Simulation: Operational Concept, " draft (Orlando, FL 199), p 15, describes types of PDUs and functions originally used in SIMNET.

[3] U.S. Army, Simulation, Training, and Instrumentation Command, "Battlefield Distributed Simulation-Developmental Advanced Technology Demonstration Technology Development Plan, " draft (Orlando, FL: September 1993), p 4.

due care had been exercised in developing a simulation plan for the generation of simulation data to be furnished to the DAB for use in acquisition decisionmaking. It comes close to being an accreditation procedure, except for the fact that, in accordance with DoD Directive 5000.59, only the user of M&S results—in this case, the DAB-can *accredit* a model or simulation. The EXCIMS can endorse, but cannot accredit, use of a model by the DAB for support of acquisition decisionmaking. The Simulation Endorsement Process could be, but is not necessarily, a validation procedure; nor is it claimed to be a validation procedure.

STANDARDS FOR DIS

The simulators, computers, and network links used for DIS would not work together unless they were all designed to have compatible interfaces—i.e., to comply with interface standards. Several types of standards are needed for DIS. Industry standards and military standards for computer

BOX 10: Protocol Data Units (PDUs) (Cc

DIS 1.0 PDUs	Additional PDUs Proposed for DIS 2.0	Additional PDUs Considered for DIS 3.0
Entity state	Emission	C^3I
Fire	Laser	Dynamic terrain
Detonation	Transmitter	Weather/atmosphere
Service request	Signal	Fidelity controls
Resupply offer	Simulation management	Transfer control
Resupply received	Create entity	Aggregate/deaggregate
Resupply cancel	Remove entity	Instrumentation
Repair complete	Start/Resume	
Repair response	Stop/Freeze	
Collision	Acknowledge	
	Action request	
	Action response	
	Data query	
	Set data	
	Data	
	Event	
	Message	

SOURCE: Office of Technology Assessment, 1995.

equipment and software are specified for DIS exercises. However, the DIS community has had to invent the standards that are unique to DIS. These include standards for protocols (procedures and message formats) for communications among simulators and standards for exercise management.

To some, the entire issue of standards for DIS revolves around the creation of standards for the message packets called protocol data units PDUs that are transmitted from simulator to simulator over the network (see box 10). If these are not well designed, the simulation will not run properly, or will cease to run at all. Enunciation of such standards was a primary goal of the SIMNET program from its very beginning. Refinement and testing of DIS continues as a community-wide activity. Industry adoption of DIS protocols has led to the availability of a variety of interoperable simulators (see box 11).

Standards are not an unqualified good, especially if compliance is mandatory, because they are the result of *compromises among users* that may or may not be worth making. Standard-setting usually falls to an organization that can set and manage standards and facilitate making simulations available to program managers who need them. While it might be easy to get agreement on the need for such an organization, what the standards should be and who should manage them is not easily agreed on. The Army, having taken leadership in the development of DIS technology with the SIMNET program, called for a single manager that "will need to be the 'policeman' of the system with respect to giving the equivalent of the 'Good Housekeeping Seal' to configuration models of users' systems that wish to interact throughout the system, and the keeper of the standards and protocols that form the electronic gateway into the electronic battlefield" (170, p. 21). Among the other military services, there was concern that the Army might be named the manager (115). Had this happened, it might have perpetuated a service bias to validation of simulations and restricted access to the DIS platforms on which the simulation exercises were performed.

BOX 11: DIS Interoperability Demonstration at the I/ITSE Conference

Industry's acceptance of the DIS 1.0 protocols was demonstrated dramatically in November 1992 at the Interservice/industry Training Systems and Education Conference (I/ITSEC) in San Antonio, Texas. According to the DIS Steering Committee, "the I/ITSEC is the training and simulation community's major annual gathering. Part of the conference is a large trade show to which all the major modeling and simulation contractors bring their wares. In the past all the simulators demonstrated did so on a stand-alone basis. During the 1992 show [more than 30] simulators, computer generated force devices, and monitoring devices, from [more than 20] organizations, were linked together [by Ethernet] using the basic DIS PDUs The virtual world consisted of a military base near the Pacific ocean (Fort Hunter-Liggett) and the adjacent waters. The scenario included maritime, air-to-air, air-to-ground, ground-to-air, and land operations in which all the players took part. " This was the "first major test" of the DIS standard protocols and communication architecture.[1]

The simulated platforms and weapon systems included E-2Cs, F/A-18s, AH-64 Apache helicopters, M1 tanks, a Dragon antitank missile, a Patriot antiaircraft missile, the U.S. S. *Ticonderoga,* the *U.S. S. Perry,* the *U.S. S. Wasp,* and Soviet-made SU-25 attack aircraft.[2] Most of the simulators had been designed for other purposes before SIMNET, and many—including SIMNET simulators that used the SIMNET protocols—had to be outfitted with separate boxes to translate messages into DIS protocol data units. Experts had predicted it would take much longer than two years to independently develop protocols that could be exchanged across the network quickly enough for interaction in real time.[3] In this case the exchange happened in real time even with some of the simulators translating protocols. It was proof that industry could fully participate in the DoD simulation network, which is a necessary step towards use of the network for design, virtual prototyping, and evaluation for procurement.

In a separate simulation, live tanks at Fort Hunter-Liggett exercised with simulated vehicles. Observers at the I/ITSEC could watch on a big screen either a view of the terrain televised by a camera on top of a tank (roughly what the live tank crew saw) or a computer-generated image of the virtual battlefield from the tank's point of view (roughly what a tank simulator crew would see).

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[1] DIS Steering Committee, *The DIS Vision, A Map to the Future of Distributed Simulation*, version 1, IST-SP-94-01 (Orlando, FL The University of Central Florida, Institute for Simulation and Training, May 1994).

[2] L. D. Voss, *A Revolution in Simulation: Distributed Interaction in the '90s and Beyond* (Arlington, VA: Pasha Publications, Inc., 1993), p 106

[3] K Doris, presentation, Intersewlce/industry Training Systems and Education (I/ITSE) Conference, San Antonio, TX, November 1992

SOURCE: Office of Technology Assessment, 1995

Probably these concerns have been alleviated by the recent establishment of the DMSO Architecture Management Group, which will specify a high-level architecture, including standards, for DoD distributed simulations. The AMG is expected to specify the use of the DIS protocols developed in the DIS standards workshops at the University of Central Florida's Institute for Simulation and Training (see box 12).

To standardize the VV&A of simulations, benchmarking procedures may have to be defined. Proposed solutions vary. The National Security Industrial Association has suggested that "we must depart from the concept of optimized weapon systems and relative values. . . One way to enforce this change would be to designate a scripted benchmark which any simulation should be able to replicate in terms of two forces of particular di-

BOX 12: DIS Standards Workshops

Standardization of DIS simulation and communications protocols insures interoperability of all hardware and software that complies with the standard protocols, DoD decided in 1990 to use industry-standard simulation protocols if suitable ones existed, and the SIMNET protocols were upgraded to a new standard known as the DIS 1.0 protocols, The new standard was been widely accepted throughout the simulation industry, as was demonstrated in 1992 when very different simulators from over 30 different companies were interactively networked using the draft DIS 1.0 protocols in real time. A DIS community representative asked the Standards Board of the Institute of Electrical and Electronics Engineers (IEEE) to adopt the DIS 1.0 protocols as an IEEE standard, and it did so in 1993, The IEEE standard, called IEEE 1278 -1993,1 was subsequently *recognized* (i.e., endorsed), by the American National Standards Institute (ANSI). This doubtless averted proliferation of competing standards and concomitant problems of noninteroperability.

The protocols need to be revised as telecommunications and computing technologies advance. Some of the protocols used for DIS are widely used and fairly stable. Examples include the basic wide-area networking protocols used by the Internet; these are called the TCP/lP protocols, after the acronyms for two of them, the Transmission Control Protocol and the Internet Protocol. However, the application-layer protocols used only for DIS are revised frequently, New experimental versions of the DIS protocols are defined by Government, industry, and academic participants at DIS standards workshops hosted by the Institute for Simulation and Training (lST) at the University of Central Florida.[2] This process allows both military requirements and the profit motive to motivate the development of protocols that are usable by many types of applications and by systems embodying a variety of technologies,

Experimental versions of the DIS protocols are tested in DoD excercises, and perhaps elsewhere, If satisfactory, a version may be proposed for adoption by the IEEE Standards Board. If adopted, many domestic and foreign companies may produce simulation and networking hardware and software that complies with the standard, increasing the options for nondevelopmental procurement of such products by DoD. Standards adopted by the IEEE may be recognized by ANSI or adopted by the International Electrotechnical Committee (lEC) of the International Organization for Standardization (ISO).

Balloting groups of the IST standards working groups have recently approved the proposal of two draft DIS standards to the IEEE Standards Board. The first, P1278.1, is a standard for protocols; the second, P1278.2, is a standard for communications. The respective working groups are struggling to resolve most balloting comments (suggestions and reservations) in time to submit these draft standards to the IEEE Standards Board in August for consideration at its September 1995 meeting.[3] If they are adopted this year, they will become IEEE standards IEEE 1278.1-1995 and IEEE 1278.2-1995 and wilI complement IEEE 1278-1993. Balloting for a draft standard for exercise management and feedback, P1278.3, ended June 30, but tabulation of the results and resolution of comments has not been completed as this background paper goes to press (July 1995).[3] If it is adopted in 1996, it will become IEEE standard IEEE 1278.3-1996.

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[1] Institute of Electrical and Electronic Engineers, *IEEE Standard for Information Technology---Protocols for Distributed Interacrive Simulation Applications, Entity Information and Interaction,* IEEE Standard 1278-1993 (Piscataway, NJ IEEE Customer Service Center, 1993).

[2] Details are on the World Wide Web at <URL.ftp://ftp.sc.ist.ucf.edu/public/STDS/workshop/>

[3] M. Loper, personal communication, July 17, 1995.

SOURCE: Office of Technology Assessment, 1995 mensions engaging one another. . . [ARPA's 73 Easting, a simulation recreating a battle of the Persian Gulf War, is an example of] an excellent first step in developing dynamic simulation benchmarks'' (101, p. 39).

Ultimately, the limitation of using modeling and simulation throughout the development life cycle of a system is the difficulty in relating program measures of performance to those of system effectiveness and finally to measures of force effectiveness. Each organization—analytic, combat development, training and doctrine, test and evaluation—uses its own measurement tools and has its own perceptions of how to measure the effects. In order to pass on lessons learned, share models and modeling tools and resources, and coherently track systems through their life cycle process, mutually acceptable tools, common data dictionaries,[48] and common measures of effectiveness must be coordinated (101, p. 40).

Without such benchmarking, different simulations used to predict system effectiveness give disparate results. One simulation may indicate that proposed system X would increase the effectiveness of an armored division, in a particular scenario, by half, while another simulation may find no significant effect. Such occurrences sometimes lead to allegations of biases in ''legacy'' (long-used, service-sponsored) simulations. However, not all differences in preference deserve the perjorative term ''bias.'' Differing roles and missions can lead to some very defensible differences in preference. The test and acquisitions communities illustrate this point: the approaches of the two communities are in direct opposition to each other. The acquisition community uses relative changes in outcome as their primary measure of effectiveness (MOE). Scenarios are normalized with optimal operation assumed for all weapons to better detect inherent differences when comparing different systems, models, or designs. These simulations are not necessarily intended to reflect reality. The testing and training communities, however, seek a realistic representation of the fog and friction of war (101, p. 3). These differences stem from the communities' differing missions: the acquisition community seeks the best item, or the best item for the money, while the testing community seeks the Achilles heel of a given item.

SCALABILITY AND SCALING

The draft *DoD Modeling and Simulation Master Plan* (195) defines *scalability* as ''the ability of a distributed simulation to maintain time [sic] and spatial consistency as the number of entities and accompanying interactions increase'' (cf. (27)) It is desirable that DoD distributed simulations be scalable, e.g., in order to provide large forces for high-echelon commanders to command. To this end, ARPA at one time wanted 100,000 entities to be networked in its Synthetic Theater of War program (162,164). It is also desirable that distributed engineering simulations, such as those being developed for ARPA's Simulation-Based Design program, be scalable to encompass, e.g., simulation of all systems on a ship (147).

However, there is a limit to the number of entities that can participate in a distributed simulation without causing loss of temporal consistency—i.e., desynchronization.[49] The limit is not a constant of nature, like the speed of light; it may be raised by improving hardware, software, communications architecture, and exercise management (7, 39, 81,102, 125, 130, 132). However, it is a real limitation, one that is recognized by the draft *DoD Modeling and Simulation Master Plan*.

Limits to scalability were encountered in the STOW-E exercise, even though STOW-E set a new record for DIS scale (over 2,000 simulta-

[48] Data dictionaries are documents that define and identify needed data. An entry in a data dictionary specifies what the name of a data set means, what the data are used for, where the data are stored, how the data are transferred and used, and the form they are put in.

[49] There is also a limit to the number of types of entities, although this is a limit imposed more by the affordability of pre-exercise simulation development than by run-time constraints. See reference (117).

neous entities) by demonstrating several effective communications techniques that had been proposed (27) to widen PDU traffic bottlenecks; these included bundling,[50] compression,[51] multicasting,[52] and the use of ‘‘delta-PDUs’’ (PDUs that announce changes rather than status). One analyst of STOW-E data wrote that ‘‘in some machines, computer processing was overloaded after entity counts reached 1,000, with others having a slightly higher threshold’’ (119).

OTA staff observing STOW-E at ARPA’s WISSARD (What If Simulation System for Advanced Research and Development) facility and other sites noted that some briefers described the STOW program as having a goal of netting 50,000 entities in its STOW-97 demonstration (a change indicating greater concern about scalability), while other briefers still quoted the original goal of netting 100,000 entities. ARPA’s World Wide Web page describing STOW efforts still says the goal is netting 100,000 entities (164).

Even if it were technically feasible to have 100,000 tank simulators drive and fight on the same virtual battlefield, they would not represent real divisions or corps (or higher echelon organizations) unless each small unit’s ‘‘slice’’ (share) of division- or corps-level intelligence, communications, logistics, and other support functions is modeled. That is, balanced representation of different types of entities is necessary for fidelity.

Attempts to increase fidelity by simulating more details—e.g., of radio signals, or a dismounted soldier’s pose—will also stress scalability. Other things being equal, simulating more detail will require simulating fewer entities.

FUNDING FOR DIS SYSTEMS

It is difficult to estimate how much DoD spends on combat modeling and simulation, partly because there are disputes about how much of the Department’s various activities are modeling and simulation, and partly because much modeling and simulation—including combat modeling and simulation—is performed as an integral part of acquisition, operations, and maintenance and is not funded as a separate account. This section reports some estimates of funding for modeling and simulation, especially for DIS.

Research and Development

The Modeling and Simulation Technology Area Assessment (TAA) prepared by the Office of the Director of Defense Research and Engineering in 1994 (186) tallied and proposed DoD investment in *development* of models and simulations. Development of the 1994 M&S Technology Area Plan (TAP), conduct of the 1994 M&S Technology Area Review (TAR), and production of the 1994 M&S TAA were DoD’s first attempt to comprehensively analyze and plan the course of development of M&S technology. In the process, DoD discovered that the Army and ARPA treated M&S as a unique technology area; while the Air Force, the Navy, and the Ballistic Missile Defense Organization (BMDO) considered M&S development

[50] *Bundling* is the concatenation of the information fields of several datagrams addressed to the same destination into one longer information field, which requires only one header and set of flags. This reduces network congestion but requires delaying transmission of the resulting packet until its information field is filled with the component information fields.

[51] *Compression* is the coding of information in a datagram so as to reduce the number of characters required. The basic principle is to use the shortest code words for the character strings that occur most frequently in the uncompressed data. In DIS exercises such as STOW-E, compression has reduced packet size to 4 or 5 percent of the uncompressed size, in effect increasing the number of simulators that can participate by a factor of 20 or 25.

[52] *Multicasting* is the addressing of packets to an interest group rather than to a particular computer, or as had been done in SIMNET, to all computers. Thus a gateway between a WAN (such as the Defense Simulation Internet) and a LAN connecting aircraft simulators can be programmed to ignore packets arriving from the WAN that are addressed to an acoustic emissions interest group; that is, the gateway will not pass them on to the LAN, which serves no simulators that need to receive them. This reduces congestion of the LAN.

TABLE 5: Funding for Research and Development of Modeling and Simulation, by Technology Sub-area

	($ millions)		
subarea	FY 1994	FY 1995	FY 1996
Architecture & standards	$114.8	$88.2	$83.4
Environmental representation	68.4	76,4	64.9
Computer generated forces	44.4	54.4	49.9
Total	$227.6	$219.0	$198,2

SOURCE” Department of Defense, Defense Modeling and Simulation Office, 1994

as supporting technology (tools) for other programs. The Joint Directors of Laboratories (JDL) had not kept track of laboratory spending on modeling and simulation as a separate account. The TAA concluded that, because of the “confusion” then existing among the DoD Components over the distinction between M&S technology development and M&S applications, the first TAA is probably incomplete and “significant 6.2-6.3 funded M&S technology development work, beyond that reported in the TAR, is being conducted in support of other technology areas, as well as in 6.4 funded Demonstration and Validation programs” (186). Nevertheless, the TAA concluded that preparation of the first TAP, TAR, and TAA was very productive for DoD’s M&S community. It identified many excellent programs as well as areas needing increased emphasis. “The TAR, in particular, offered an excellent forum for cross-fertilization among components and among programs within components. The lessons learned from this initial effort will yield significant improvements in subsequent TAPs, TARs, and TAAs ” (186). The 1995 TAP is expected to be released shortly after this background paper is completed.

Despite its warning of incompleteness, the 1994 TAA tallied M&S Technology Area funding of approximately $232 million in FY 1994, $231 million in FY 1995, and $226 million in FY 1996, before adjustments were made by and overhead expenses were deducted for the Office of the Secretary of Defense. The TAA identified the funding of several projects in nine program elements. The TAA panel binned the funding into three “subareas” of technology flagged as meriting special emphasis: Architecture and Standards, Environmental Representation, and Computer Generated Forces. (See table 5.) These subareas are critical to the development of distributed simulations, including DIS.

The Defense Modeling and Simulation Office’s own 1995 Modeling and Simulation Investment Plan projects a doubling of funding, from about $5 million in FY 1995 to about $10 million in FY 1996 (67, slide 38). (See table 6.) All of the activities listed support DIS; one—the DIS enumeration document—is exclusively for DIS.

Another DIS-related project is the Universal Threat System for Simulators (UTSS), which will build a data repository for threat data required by the supported simulators. It will also build a Real-Time Simulation Software (RTSS) library that will host reusable, validated simulation software and will catalog available threat simulations (144). The initial data modeling effort, now complete, was gathering detailed data requirements for each of the four simulators selected for inclusion in the initial development of UTSS: the Army’s Modular Semiautomated Forces (ModSAF), the Navy’s F-14D Weapon Systems Trainer, the Marine Corps’s UH-1N Weapon Systems Trainer, and the Air Force’s F-15C and F-16C UTDs. The project, formerly a program, received funding from DMSO in FY 1993 and FY 1994. It is now funded solely by the Navy, as project W2124 of program element 0204571 N, Consolidated Training Systems Development (122), for which DoD budgeted $48 million in FY 1996 and $38 million in FY 1997 (190).

TABLE 6: The Defense Modeling and Simulation Office's Investment Plan
($ thousands)

	FY 1995	Estimated FY 1996
Functional Data Administrator (FDAd)[a] support	$1,184,5	$2,900.0
Model and Simulation Resource Repository (MSRR) project[b]	1,443.8	5,700.0
Data verification, validation, and certification tasks	680.0	1,000.0
Authoritative data sources (ADS), portable data quality tool,[c] and C* core data model integration	300.0	—
Modeling and simulation community directories	411.0	—
Data security	575.0	1,000.0
DIS enumeration document[e]	533.0	—
Total	$5,127.3	$10,600.0

[a] The Defense Modeling and Simulation Office (DMSO) has been designated the Modeling and Simulation Functional Data Administrator (M&S FDAd).

[b] DMSO has established a MSRR on the World Wide Web at Uniform Resource Locator (URL) <URL:http://www.dmso.mil/dmso/msrr.html> as part of the DoD Data Repository System. It has hypertext links to other MSRR nodes, including the DMSO Interim MSRR hosted on the Joint Data Base Elements for Modeling and Simulation node at the U.S. Army Electronic Proving Ground at Fort Huachuca, Arizona, at <URL:http://huachuca-jdbe.army.mil/>.

[c] The supported activity is making computer software used for data verification at U.S. Central Command portable, i.e. , capable of being used on a variety of computers

[d] Modeling and simulation community directories enable M&S developers and users to locate authoritative data sources, databases, models and simulations,

[e] The latest version of what is commonly called the DIS enumeration document Is: Institute for Simulation and Training, *Enumeration and Bit-encoded Values for Use with IEEE 1278.1 Standard for Distributed Interactive Simulation—Application Protocols,* IST-CR-95-05 (Orlando, FL: Institute for Simulation and Training, 1995). Available online at <URL:ftp://ftp.sc.ist.ucf.edu/public/STDS/enum/enum95.doc>, filedate Mar 21, 1995.

SOURCE: Department of Defense, 1995.

Procurement

DoD has not tallied funding for procurement of modeling and simulation equipment and services in general or for DIS in particular. In the past, no need for such an accounting was recognized, and doing it would be problematic because of definitional difficulties. An expansive definition of simulation says that "everything is simulation except combat" (191). According to this definition, most of the defense budget is for simulation, but less expansive defininitions of simulation would count only a small fraction of the defense budget as funding for simulation, and only a fraction of that would be funding for DIS. However, as the Army proceeds with its program of "digitizing the battlefield" and as DoD, guided by the MSMP, proceeds to interface live forces, constructive simulations, and distributed simulations to one another and to the Global Command and Control System—so that forces can train at home and when they deploy—it will become more difficult to identify systems that are not from time to time involved in DIS.

Thus again at the risk of undercounting, we can mention some of the largest DIS-related programs in the DoD Comptroller's 1995 *Procurement Programs* (P-1) report. Top ranked (in terms of FY 1997 funding) is SIMNET/Close Combat Tactical Trainer, for which $88.5 million is requested. The Close Combat Tactical Trainer (CCTT), a descendant of SIMNET, is the first of several planned Army DIS programs that are collectively called the Combined Arms Tactical Trainer (CATT) program. Its aim is to network simulators for a variety of Army combat platforms for the purpose of collective combined arms tactical training. The second CATT program, which ranks second among DIS programs in FY 1997 P-1 funding, is the Fire Support Combined Arms Tactical Trainer (FSCATT), for which the Army has requested no procurement funds through FY 1996; but the Army has requested $22 million in FY 1997.[53] Next is the Reconfigurable Simulators program (see figure l-8), for which the Army has requested about $17 million in FY 1997. Some of the "simulators, all types," for which the Army requested about $8 million in FY 1997, might be used for DIS on occasion.

Operations

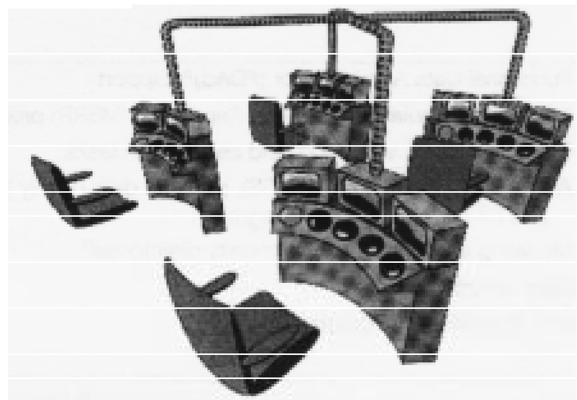
Defense authorization and appropriation bills typically provide little specific direction on funding for modeling and simulation.[54]

The National Defense Authorization Act for Fiscal Year 1995 (Public Law 103-337) authorized $89.1 billion, and the Department of Defense Appropriations Act, 1995 (Public Law 103-335) appropriated $80.9 billion, for operations and maintenance, including training. The fraction spent on DIS activities is unknown but presumably very small.

DARPA's SIMNET program ended in 1989, but the simulators, communications protocols, and network developed by the program are still being used and upgraded by ARPA's Advanced Distributed Simulation (ADS) program, the Army's Battlefield Distributed Simulation-Developmental (BDS-D) program and other Department of Defense (DoD) programs. The *name* SIMNET still occurs in the "SIMNET/Close Combat Tactical Trainer" line item in the DoD Comptroller's 1995 *Procurement Programs* (P-1) report to Congress (189). The term is still applied to simulators, networks, and simulations that still use the SIMNET communications protocols, which have been superseded by the Distributed Interactive Simulation (DIS) protocols.

A distributed interactive simulation is "distributed" in the sense that simulator computers at multiple training sites nationwide are connected by means of a local-area network (LAN; see figure 2), which in turn maybe connected to a wide-area network (WAN) such as the the Defense Simulation Internet (DSI) (see figure 3). Trainees can enter disparate tank, helicopter, or other simulators and all participate in the same simulated combat. The simulation is "interactive" in the sense that humans interact with the computers to influence the simulation. The battle does not follow a set script, and trainees win or lose on the basis of their performance. The trainees fight a similarly networked opposing force, which may be a combination of *virtual* forces-real people operating simulators-and semiautomated forces (SAF)---vehicles and weapons simulated by computers with humans providing operational supervision. In both the virtual forces and the semiautomated forces, human behavior is simulated by humans, albeit humans not affected by the many stresses of real combat.

FIGURE 8: Reconfigurable Simulators (Artist's Conception)



SOURCE: U.S. Army Simulation, Training, and Instrumentation Command.

[53] FSCATT is one of five acquisition programs that the Federal Acquisition Streamlining Act of 1994(Public Law 103-355) authorized the Secretary of Defense to designate as a "pilot" program to determine "the potential for increasing the efficiency and effectiveness of the acquisition process using standard commercial practices" (148, p. 65).

[54] The National Defense Authorization Act for Fiscal Year 1994 (Public Law 103-160) did authorize appropriation of $75 million for procurement of simulation equipment for reserve components.