1-1-1993

Simulator Networking Handbook: Distributed Interactive Simulation Testbed

Brian Goldiez

INSTITUTE FOR SIMULATION AND TRAINING

Contract Number N61339-91-C-0103
STRICOM
March 11, 1993

SIMULATOR NETWORKING HANDBOOK

Distributed Interactive Simulation Testbed

Institute for Simulation and Training
12424 Research Parkway, Suite 300
Orlando FL 32826

University of Central Florida
Division of Sponsored Research

IST-TR-93-08

SIMULATOR NETWORKING HANDBOOK

Distributed Interactive Simulation Testbed

Prepared for:
U.S. Army Simulation Training and
Instrumentation Command
12350 Research Parkway
Orlando, Florida 32826-3276

March 11, 1993

IST-TR-93-08

Contractor:
University of Central Florida
Institute for Simulation and Training
12424 Research Parkway, Suite 300
Orlando, Florida 32826

Primary Author: Brian Goldiez
Brian Goldiez

Contributing Authors:
Scott Smith, Margaret Loper
Dan Mullally, Curt Lisle, Huat Ng
Gamini Bulumulle, Dr. Bruce McDonald

Table of Contents

1 Background

This handbook is an attempt to collect and organize a large body of knowledge regarding the design and development of simulation networks. It draws on the experience of a number of participants in several recent large-scale efforts aimed at advancing the state-of-the-art of Distributed Interactive Simulation (DIS).

1.1 The origins of this document

Simulator network technology is developing rapidly. Standards are being created which define the messages and communication mechanisms to be used to connect heterogeneous simulators. In addition, these networks are being expanded to include event stepped simulations and operational hardware. Although these networks have grown from the military training community, the number of applications of similar networks is unbounded.

The variability and options inherent in what is standardized, coupled with the choices of simulation related features, which are not and cannot be standardized, lead to many choices available to configure simulator networks. These choices result in the requirement to create guidelines which can be used by those wishing to create simulator networks.

This handbook is intended to guide organizations wishing to develop simulator networks. It briefly explains the current progress in simulator networking. The main intent of this document, though, is to guide those wishing to create and operate a simulator network using the evolving set of DIS protocols and communications structures. The body of the document attempts to provide a general overview of each topic being covered and then delves into detailed considerations within a particular topic. The last section is a chronological case study of a specific simulator network implementation.

Simulator networking is a hybrid technology that is maturing. It melds the two technologies from which its name is derived: simulators and networks. Simulators are computer based systems which provide artificial conditions for performing some task. The terms "simulator" and "player" are used interchangeably in this handbook. The degree to which the conditions are made artificial depends on factors which include, but are not limited to, cost, environmental considerations, and safety.

There are many tasks which can be performed in a simulator, including training, analysis, and testing. Networks provide a mechanism simulators may use for communication. There are

many types of these, including computer networks, voice networks, and imaging networks. Connecting simulators via networks provides a means to have many players interact in artificial conditions. The domains of simulator and communications applications and technologies are growing; however, the growth in each domain is being achieved in isolation from the others.

When simulation and networking are combined, the domain of application of simulator networking also becomes a rapidly expanding domain. To date, most simulator networking research, development, and demonstrations have been greatly heralded and promoted but poorly documented. The broad community has derived little benefit from the efforts of others. This handbook has been created to capture the state of knowledge necessary to create a simulator network.

This document divides simulator networking into four areas: the network, the simulator, the environment, and the intended use. Overriding these four areas are matters related to systems design, testing, and operations.

1.2 The evolution of simulator networks

Simulator networks have been in existence since the early 1980's. The first simulator networks used distributed processors and shared memory to configure the network. Figure 1. depicts such a network environment. These systems worked well for their intended purpose: training small groups of individuals in high fidelity flight simulators.

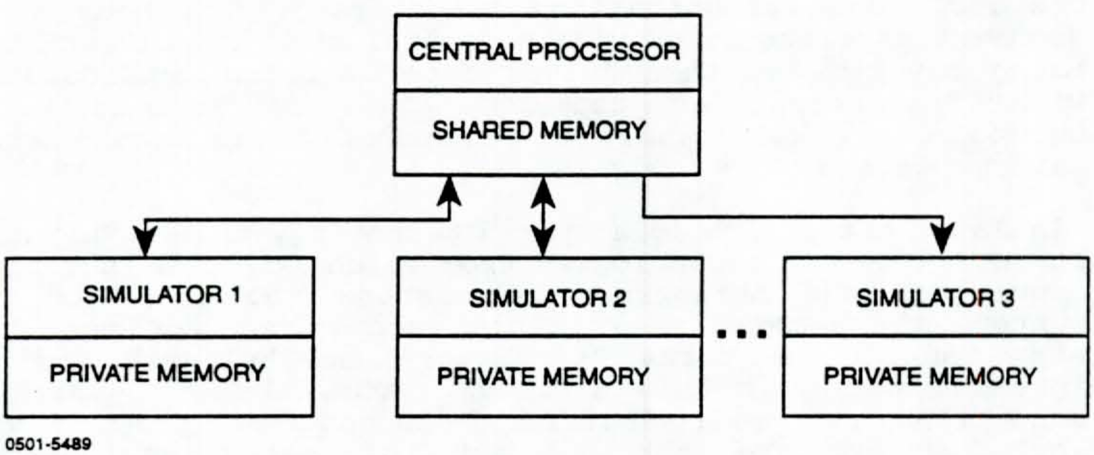


Figure 1. A Shared Memory Network

These early systems were limited from several points of view. The first limitation was hardware and software compatibility.

If one wanted to interface a simulator to this network, then its computer hardware and software had to be compatible with the baseline simulation system. However, achieving hardware and software compatibility did not assure a new player could enter these early networks. One reason was early networks were synchronous systems.

Synchronous systems using shared memory require regular system updates and time slicing of data arrivals. Regular system updates occur at preset times and are phased into the appropriate software cycle. Time slicing of data assures that data being stored or fetched from memory is delivered or retrieved without contention. For these reasons, adding simulators to early networks after the design phase was not practical.

Simulator networks continued to evolve. The development of reflective memory allowed additional flexibility in simulator networks. Figure 2 depicts one of many reflective memory arrangements applicable to simulation. In reflective memory systems, different processors retain selective copies of the information in other processors. Writing to memory entails writing to several memories in different computers. Writing is normally implemented through some computer vendor specific bus structure. Reading is performed by a computer from its own private copy.

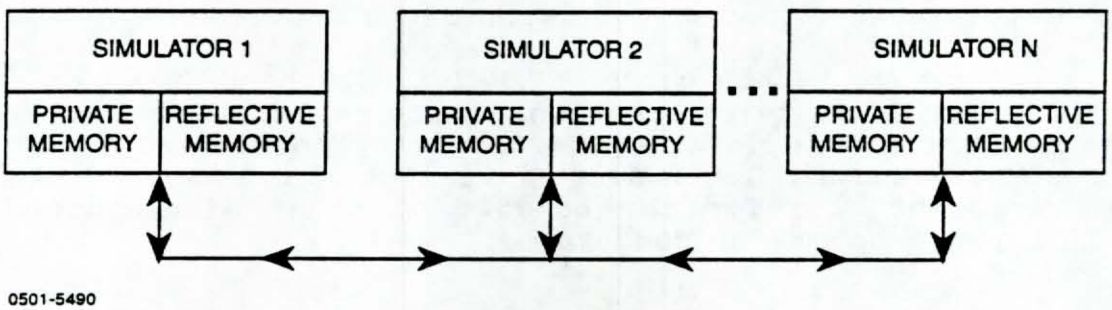


Figure 2. A Network Using Reflective Memory

Reflective memory systems enhance modularity and flexibility as compared to shared memory architectures. Modularity and flexibility are the result of redundant memory. Referring to Figure 2 again, one can deduce the benefit of redundant memory. Redundant memory provides a mechanism to allow other players onto the network assuming the hardware and the addressing scheme for the new player is similar to that of existing players (i.e., common hardware). Reflective memory also provides an opportunity, through an appropriate design,

for the simulators on the network to be separated and to perform their functions autonomously.

1.2.1 SIMNET

The Defense Advanced Research Project Agency (DARPA) developed the SIMulator NETworking (SIMNET) project in the middle of the 1980's. This program furthered modularity of simulator networking on several fronts.

The first front introduced the concept of "Selective Fidelity." Selective fidelity provides simulators with only those features necessary to support collective operations. For example, SIMNET simulated only the basic vehicle dynamics of the M-1 Tank. High fidelity in vehicle dynamics was not necessary because it would have provided only marginal enhancements to the collective operation of several simulators.

Second, SIMNET developed an asynchronous message passing scheme. Information was sent only when the state of the simulator changed or after some predetermined time (e.g., 5 seconds).

The third front which SIMNET influenced was in the use of commercially available networking technology. SIMNET used the Ethernet Standard and later moved to IEEE802.3, Carrier Sense Multiple Access with Collision Detection (CSMA/CD.)

The final front which SIMNET influenced was to extend replicated state information. Where reflective memory systems replicated the information necessary to several simulators, SIMNET used simulator state variables to create a simple state representation for the benefit of other simulators in the player's sphere of concern.

1.2.2 DIS

DIS is the current extension to simulator networks. DIS achieves a true open architecture for simulator networks. The Applications Level Standard [IST-PD-91-1] describes the first of four standards which are being developed to describe the DIS environment. DIS extends the simulator networking design along several fronts, which are explained briefly below and in detail in Sections 4, 5, and 6.

First, DIS further separates the content of messages from the underlying communications hardware and software used to transmit them. SIMNET relied on a proprietary communications protocol, the Association Protocol (AP) [BBN,1991]. DIS, on

the other hand, will utilize well known and commercially available protocols wherever possible.

Second, DIS extends the domain of the simulation application by paralleling events as they occur in nature. For example, the earth in a DIS application is an oblate ellipsoid, while in SIMNET the earth is flat. DIS does not inherently constrain the sphere of concern or degree of realism which a player may portray. The notion of selective fidelity is not a constraint in a DIS network.

Third, DIS supports networks of heterogeneous simulators. The standard will be written to be hardware independent.

2 Introduction

This document is intended to guide those developing simulator networks. As will be seen throughout this handbook, there is no single set of equations which one can use to obtain all of the answers needed to design a simulator network. Where equations, algorithms, or heuristics exist, they will be provided or referenced. Section 3.2 presents a methodology to guide the designer to ensure that all aspects of the simulator network system have been considered.

The design of simulator networks is new and complex. It melds two technologies which have many options available to meet a specific objective. When the two technologies are merged, the number of options increases geometrically. Therefore, it is important to realize that in the design of simulator networks there is no one right answer. Many approaches will reach the same outcome. It is important that one approach be selected to meet the specific needs of both the users and the providers of the system.

Often when a system is developed, the providers and the users of the system have only vague ideas of the specific attributes which should be contained in the final product. The specific attributes of the final product reveal themselves during development. Therefore, the design must evolve, especially when many options are available.

2.1 The Domain of simulation

Simulate is defined [MERRIAM,1986] as:

> "To assume the outward qualities or appearance of, often with the intent to deceive."

Simulation is the act or process of simulating. This definition is extremely broad and must be constrained to a domain of interest. Therefore, in this handbook, the domain of simulation is restricted to portraying the qualities or appearance of a series of events which can occur in an artificial environment. Whether the events can be related to a physical event or process is not essential to creating a simulation.

Simulation, per the above definition, can include many things. In the military context of interest, simulation can include so called war games which are event stepped models of conflict, real time simulations of events which are time stepped models, and the use of operational equipment in mock battles.

Our goal is to be able to create networks of all simulation types. However, the focus of this handbook is to create networks of time stepped simulation models. Therefore, time stepped simulation defines our domain of interest with respect to simulation. As technology matures, the other aspects of simulation will be included.

The area of time stepped simulations is quite large. Simulators in this category run the gamut from large flight simulators in engineering laboratories to simulators such as MicroSoft™ Flight Simulator. Simulations in this category include the modeling of items using time as the major event to update the simulation. The time internal to the simulation and the resulting simulator response must both match the actual system within some degree of accuracy. The amount of accuracy is used to define the term "fidelity" as it relates to simulation. Accuracy is also a significant factor in the cost of the simulation.

2.2 The Domain of communications

The domain of communications is also quite large and can be divided in several different ways. One may divide communications into digital or analog domains or consider whether the physical medium used to carry the communications signal is wireless or cabled. Further, one may wish to distinguish communications on the basis of higher level protocols such as reliable or acknowledged transmissions versus a datagram service. The basis of ownership of the communications media, such as common carrier versus specialized communications systems, is also an issue.

The domain of communications relevant to simulation networking is quite large. Many options are available to those wishing to create a simulator network. For the purposes of this

handbook, digital communications is considered for connection between computers and analog communications for connection between people. The physical media used and architecture selection are not factors in the consideration of communications. Clearly, the architecture should be designed to accommodate the physical medium. The architectural design of the simulator network should be consistent among all players. As discussed later, this previous statement has a significant effect on the use of repeaters, bridges, and routers. Only local area networks are considered in the scope of this handbook. However, using common carriers and modems allows for long physical distances between simulators while still operating under an extended local area network design.

2.3 Applications of DIS

There has been a perceived need that simulators operating on a network conduct their operations on a "level playing field." Such a playing field assures no simulator has an advantage over any other simulator. However, to achieve the notion of a level playing field requires that the use of simulator networks be defined. This is necessary because only the significant factors which affect the network accomplishing its mission need to be leveled.

Networked simulations have applications in many areas of interest to the Department of Defense (DoD). Networked simulations assist the DoD in enhancing readiness and safety while conserving cost. Networked simulations are particularly applicable when the above criteria are used in training, acquisition, test and evaluation, and analytical situations. If one uses a little imagination he or she can foresee networked simulation applications in the commercial sector. These areas are further explained below.

2.3.1 Training

Training benefits directly from networked simulations. This concept is supported by the Army's positive experience with SIMNET. This project, started by DARPA, continues with follow on procurements envisioned by the Army in Combined Arms Team Training (CATT) simulators and the Navy's Tactical Combat Training System (TCTS). Other indicators of training interest come from participation and follow on interest resulting from a demonstration of DIS and the Project 2851 (P2851) Common Data Base Programs at the Interservice/Industry Training Systems Conference (I/ITSEC) held in November, 1992 in San Antonio, Texas. Certainly, there must be more definitive

benefits than merely a few demonstrations which drive this interest in training.

Training, in particular the open architecture of DIS, benefits from networked simulations in several ways. First, teams of individuals can collectively experience battle and learn tactics in complete safety and on a repetitive basis if cost allows the purchase of sufficient numbers of simulators. Indeed, no one gets injured or killed in the simulators. Second, utilization of operational assets can be deferred to high priority needs. Third, diminishing range assets can be deferred to higher priority needs than routine training. Fourth, training assets can be distributed allowing for their use for purposes other than collective training and resulting in reduced logistics costs by bringing the training to the individual rather than moving people to the training sites. Finally, rapid reconfiguration of training assets provides an environment which is responsive to changing training needs or world situations.

2.3.2 Acquisition

Simulation has been used as a tool for acquisition since the early 1980's. Engineering simulations are developed to validate engineering calculations, to investigate system performance limits, to study human factors, etc. The primary benefit in using simulation is the ease and timeliness of changing parameters to optimize the design. Early design optimization is cost effective. Concurrent engineering principles are enhanced because the design can be instantiated in a virtual environment allowing early and frequent access by the design team. Simulation allows a design to be partially optimized in software before expensive hardware commitments are made.

Simulation networking brings the optimization process further along than an individual engineering simulation. When a system is prototyped and inserted in an operational setting, unforeseen problems surface. Simulation networking allows a simulation of a new weapon system to be inserted in various operational settings in a virtual environment. Operational settings in networked simulations can be structured to reveal specific parameters of the developmental system design, or the operational setting can be structured to mimic a valid battlefield environment. The result is that when problems are uncovered they can be fixed in the simulator before the prototype is developed.

2.3.3 Test and evaluation

Simulation benefits test and evaluation by providing a safe and cost effective environment. Testing can be performed without risk to human life and the environment. In addition, costs associated with conducting tests in a simulator are lower than in an operational setting. For example, the military conducts developmental and operational tests. The scope of testing in a simulator can be more extensive than in an operational setting because security and operational envelopes are easier to manage in a simulator than in an operational setting. The primary concern with using a simulator in test and evaluation is quantifying the relationship between the simulated and the operational environments.

Developmental tests are engineering in nature and typically precede operational tests. Operational tests evaluate the interactions between operator and equipment as well as the equipment's performance in an operational setting. Simulation also provides a mechanism to accumulate test type data early in the design phase. This type of data accumulation supports the acquisition process as well as the test and evaluation process.

Simulation networking expands the domain of using simulation in test and evaluation along several dimensions. First, a stable set of operational settings can be used as test environments. Second, the operational settings can be used to compare competing systems. Third, a wider set of scenarios is available to test and evaluation agencies if a reconfigurable set of simulators are available than if a single simulation environment is utilized.

2.3.4 Analysis

Analysis involves the execution of operational scenarios, the collection of data, and the review of the data after the scenario is completed. Simulation is an important tool in analysis because it is usually not feasible to execute the operational scenario due to political considerations, cost, or safety. Simulation's use in analysis has traditionally been handled using event driven war games. War games are simulations of battle where the occurrence of events advance the war game instead of time. War games are typically developed for specific analytical purposes (e.g., logistics planning or combat developments).

Networked simulations enhance analysis in two ways. First, if war games can be networked, a more generalized analytical tool

results. War games developed for specific purposes can be merged to yield more complete domains for analysis. Second, the human component can be inserted into analytical models, if networks of human operated time based simulators can be networked either with war games or can be used collectively to create an environment for analysis.

2.3.5 Other Applications

One needs only an active imagination to envision ways simulator networks can serve other communities. One can envision distributed simulations becoming integrated with theme parks, educational institutions, new product development, or medicine. One must ensure that developments in simulator networking do not preclude the other potential uses. Commercial usage will undoubtedly bring lower costs to simulation networking by bringing economies of scale to simulators as well as to networks.

3 Systems design

The scope of network simulations is very broad. There is a wide variety of simulator types which sponsors may wish to connect onto a network. There are multitudes of connection strategies which are available to connect these simulators. Also, there are many uses which may result from the simulator network. The outcome is that many options are open to those who need to create simulator networks; therefore, a systems design strategy is necessary to properly create simulator networks.

3.1 A systems design strategy

Standards address only part of the scope of simulator networks. Even so, they help implementers to sort through the available options. Standards also capture technology, reducing the risk in creating simulator networks, though they cannot possibly capture everything when technology and innovation are present. Therefore, a structured systems engineering approach is necessary to take advantage of what has been standardized, to provide for innovation, and to allow the resulting system to meet the expectations of those using the system.

The process of designing a simulation network is iterative. Iteration is necessary for a number of reasons. It is necessary when requirements cannot be succinctly stated, when technical advancements are occurring at a rapid rate, when something needs to be completed quickly, or when inexperience

exists. All of these conditions exist in creating simulation networks, and each will be addressed below.

Requirements are seldom stated succinctly. The reason is that the individual stating the requirement and the individual building the system have different backgrounds, biases, and agendas. Therefore, what is said in the requirements is important (and often subject to interpretation), along with what is not said (for any number of reasons). What results is the developer of a simulation network has to interpret the requirement in a unique, and possibly incorrect, way. Frequent interchange is needed to ensure that expectations and the resulting product are consistent.

Rapid technical development or speed of delivery are also causes for iteration. The technical community typically wants to use the most advanced systems to meet current requirements. When technology is advancing rapidly and the iterative cycle is slow (greater than 6 months), the technical community must be constrained to keep their selection of hardware and software constant. Project schedules must be kept reasonable. If project schedules are compressed excessively, decisions will be made on incomplete information, and needless iteration of the design will usually result.

Inexperience is often a cause for iteration and rework. In the case of simulation networking, there are several causes for inexperience. First, because the technologies are changing rapidly, it is difficult for individuals to keep up with technical advancements. The difficulty arises because implementing a design focuses interest, which often results in an individual becoming dated in the technology he or she implements. The other cause of inexperience is that simulator networking is new and somewhat unstable. There simply are not many individuals or organizations who can take an objective look at a problem and create an achievable design.

Experience has taught people that top down design has its place, but must be tempered with the above mentioned iteration activity. Therefore, it is recommended that simulator networks be developed through a series of rapid prototypes using design teams. This method is similar to the method of concurrent engineering.

3.2 A systems design process

The design process for simulator networks should proceed as follows:

1) Establish requirements or project objectives. Quickly define some broad requirements or objectives from the

sponsor. All members of the design team should agree with the requirements. Those requirements which cannot be agreed upon should be pursued by an activity separate from the design activity. Separation provides an environment for rapid prototype development. It is important to remember that requirements can be stated in many ways, which include utility after development (e.g., training effectiveness of the network), schedule, cost, or performance.

2) Based on the requirements stated in the first step, create a design which will meet the requirements. It is suggested that in the case of simulator networks, the design be partitioned into four areas: 1) networks, 2) simulators, 3) environment, and 4) scenario/usage. Each of these areas will be explained in subsequent sections of this handbook. A systems integration function should also be implemented to ensure the design tasks are compatible.

3) Flexibility must be a part of the design. Flexibility can be reduced in successive iterations but must be maximized early in this process. Flexibility can be achieved through several means. The means include excess capacity in computers, network bandwidth, data base features, and algorithms.

4) Implement the design. This means building something. It is very important that prototypes of the final system be built quickly. The process of building confirms what is correct in the design and quickly identifies what is not correct. A quick implementation provides valuable feedback to the requirements process and helps define the expectations of the ultimate user.

5) Baseline and document what works correctly in the implemented design and note what does not work correctly. Track baselines against the requirement. When the project objectives are complete, or when it is no longer practical to resolve documented problems, the design and prototyping process is complete.

6) Modify requirements and go back to step one.

Calendar time affects what can be implemented in a simulator network. The above mentioned iterative cycle was described with respect to technical and requirement aspects. These are the major areas affected by calendar time. The time between recognition of the need for a simulator network and actual operational capability of the network affects the iterative cycle of development. It is recommended that the calendar time be divided into 50% design/development and 50%

integration/test. A minimum of three iterative cycles are recommended. Successive iterative cycles can be at 75% of the time between previous cycles.

The preceding description delineates a process flow for creating network simulations. Additional baseline guidance is necessary to bound the problem of creating simulator networks. As stated previously, current thrusts and standards in simulator networking technology are based on DIS. Therefore, it is appropriate to obtain the desired bounding from concepts already embodied in DIS. Understanding DIS and its predecessors allows one to avoid duplicating successful and unsuccessful efforts already undertaken. The following description, therefore, has been gleaned from an operational concept document for DIS [STRICOM,1992]. The description has been modified to include any time stepped simulation network.

3.3 DIS as a system

The primary mission of time stepped simulator networks for military applications is to create synthetic, virtual representations of warfare environments by systematically connecting separate subcomponents of simulations which reside at multiple distributed locations. This type of simulator network can be used as a substitute for some field training and testing; it also allows practice of war fighting skills when cost, safety, environmental, and political constraints will not permit the field training and testing required to maintain readiness.

The property of connecting separate sub-components or elements affords the capability to configure a wide range of simulated warfare representations patterned after the task force organization of actual units, both friendly and opposing. These units represent a wide range of war fighting missions facing the U.S. and the Allied forces. Equally important is the property of interoperability which allows different simulation environments to efficiently and consistently interchange data elements essential to representing war fighting interactions and outcomes.

In effect, interoperable simulations will exchange data in a manner such that the differences in the representation of the simulated battlefield will be transparent or "seamless" as experienced by participants interacting with their particular representation of the war fighting environment. This property affords the opportunity for linking heterogeneous representations, each providing a locally consistent simulated environment, through use of buffers or translators to create a seamless interconnection. With these properties, it is

possible to have simulation components which meet special purpose local needs, and which, when required, can be linked together to form larger scale war fighting environment representations.

Seamless simulation is achieved by maintaining time and space coherency [ADST,1992-1]. The criterion for coherency is human perception in DIS. The human perception limits are defined in the DIS environment as 100 msec for closely coupled tasks and 300 msec for loosely coupled tasks [IST-PD-92-2]. These limits have been experimentally verified with human subjects [IST-TR-90-25]. The matter of space coherency is undefined and is presently an area of intense study. These properties create an environment defined as DIS.

The basic concepts of DIS are an extension of the SIMNET program developed by DARPA. The purpose of DIS is to allow dissimilar simulators distributed over a large geographical area to interact in a team environment. These simulators communicate over local area networks and wide area networks. The basic DIS concepts are:

- Event scheduling and conflict resolution are distributed,
- Simulation nodes are autonomous,
- A standard protocol is used to communicate "ground truth" data but receiving nodes are responsible for determining what they perceive,
- Simulation nodes communicate only the changes in state; Dead Reckoning is used to "smooth" the result,
- Simulation elements have public and private aspects,
- Entities are concerned with a "sphere of interaction,"
- Entities share a common gaming area,
- Model designs are parameterized, and
- Entities make synchronous and asynchronous interconnections.

The implications of each of these concepts, as they apply to DIS, are separately discussed below.

3.3.1 Distributed control

Some war games have a central computer that maintains the world state and calculates the effects of each entity's

(platform, person, missile, etc.) actions on other entities and on the environment. These computer systems must be sized with resources to handle the worst case load for a maximum number of simulated entities. DIS uses a distributed simulation approach in which the responsibility for simulating the state of each entity rests with separate simulation nodes (host computers). As new nodes are added to the network, each new one brings its own resources.

3.3.2 Autonomous simulation nodes

A DIS node is autonomous and is generally responsible for maintaining the state of one entity. In some cases, a host computer node will be responsible for maintaining the state of several Computer Generated Forces entities. As the user operates controls in the simulated or actual equipment, the host computer in that node is responsible for simulating the resulting actions of the entity using a "high" fidelity simulation model. That node is responsible for sending messages to others, as necessary, to inform them of any observable actions. All nodes are responsible for interpreting and responding to messages from other nodes and for maintaining a simple model of the status of each entity on the network. All nodes also maintain a local model of the status of the world.

3.3.3 Broadcast of Ground Truth

Each entity communicates a subset of its internal status (location, orientation, velocity, active emitters, articulated parts position, etc.) to all others. A receiving entity must use this "ground truth" to determine the effects of its presence, such as whether that entity is visible by visual or electronic means or whether it is close enough to result in a collision. The status of the other entity, <u>as perceived by the receiver</u>, is what is used to generate displays for the user on the receiving simulator.

3.3.4 Dead Reckoning

In order to limit communications, each host computer maintains a simple model of the status of every other entity (within a given range) on the network (see Figure 3). These models are periodically updated whenever their "ground truth" information is received. Between updates, receiving hosts can extrapolate the positions and orientations of the other entities based on their last reported locations, velocities, and accelerations.

Each host also maintains a similar Dead Reckoned model of its own entity. When the state of its high fidelity model differs by a given amount from its DR model, the host sends out a message describing its "ground truth."

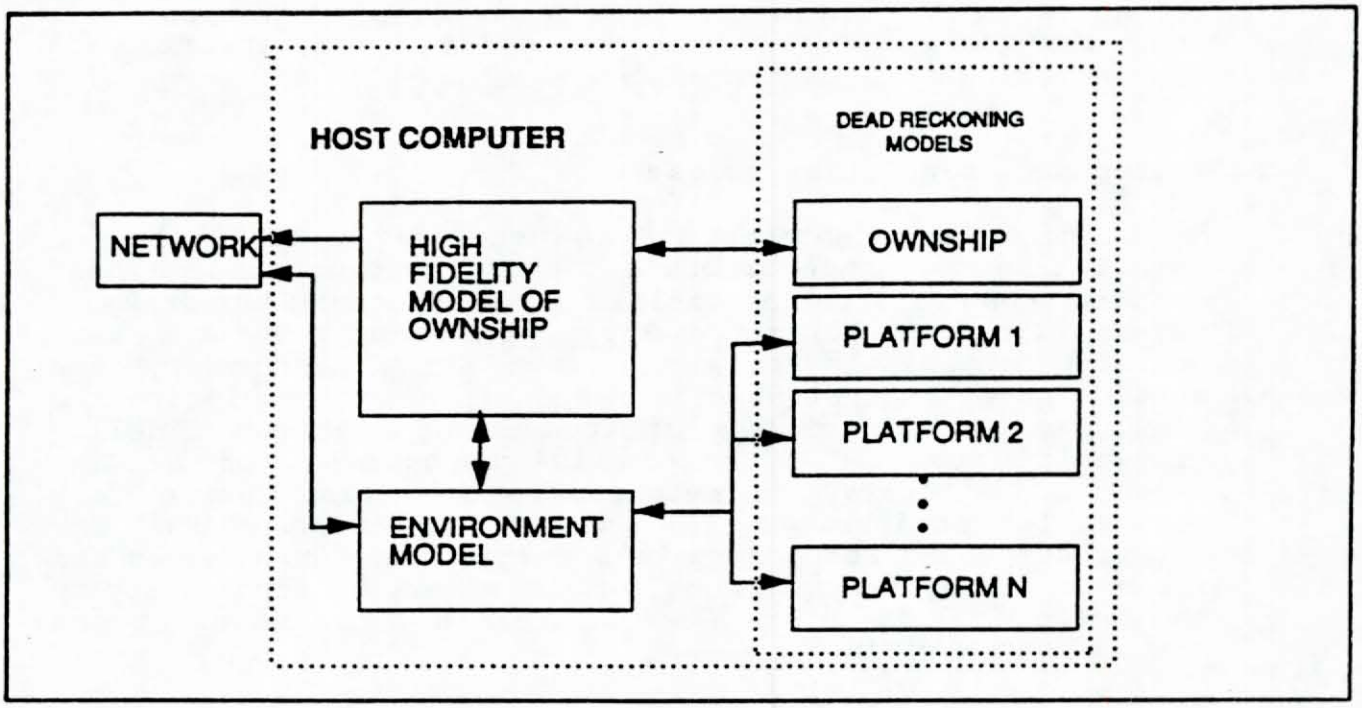


Figure 3. Dead Reckoning in DIS

3.3.5 Public and private aspects

Each simulation element will be designed as an autonomous entity. Individual entities will incorporate "public" and "private" components. Multiple entities will be connected through their public components to form simulation systems which represent virtual war fighting environments. The public component, designed as a separate module, handles the exchange of data between entities as well as any processing required to compensate for transmission delays and asynchronous arrival of data.

For the purpose of discussion, the public component will include an entity state vector and a system state vector. The entity state vector maintains current values of the variables which describe the state of the entity. The system state vector maintains current values of variables which describe the state of conditions existing across the simulation system. While the public component must be "standard" across the system, the private component creates only the interactions

and representations of the war fighting environment which are required for the simulation element created by the entity.

3.3.6 Sphere of interaction

The private component of each entity will compute an active simulation region or a "sphere of interaction." That is, for each entity, its sphere of interaction defines the spatial region in which state vector data from other entities must be monitored and processed in order to maintain the interactive simulation within the private component of the entity. Effects on the simulated war fighting environment are caused by results of actions initiated by the individual entities. Results such as collisions will be computed by the entity only when they occur within the sphere of interaction. They will subsequently be indicated by a change in the entity's state vector.

3.3.7 Common gaming area

In order to maintain ground truth within the simulation system, each host computer must share a common representation of the environment (land, ocean, atmosphere, and space). Hence, digital terrain data bases used by individual entities must, as a minimum, use the same "survey markers" as a common reference for generating terrain surfaces and overlay of cultural features and objects. Likewise, all host computers must have common representations of ocean, atmosphere, and space environment models.

3.3.8 Parameterized model designs

Model designs and algorithms used within the individual host computers to create dynamic simulations of weapon system performance, soldier machine interactions, soldier battlefield interactions, and general representation of the war fighting environment must consider that data values used in computing the models will, in part, be received from other entities in the system. Moreover, the model designs should assure that variables or parameters which affect the model performance can be redefined easily. In this manner, for example, a basic ballistics model for conventional guns could be used to represent a variety of specific weapons by changing the model parameters.

3.3.9 Synchronous and asynchronous interconnections

Conventional centrally controlled simulations use time steps to synchronize the advancement of the simulation. In these cases, computations required to determine interactions between entities and changes in entity status are completed during a prescribed time interval. The simulation is updated to reflect these changes at the end of the time interval.

In the case of asynchronous interconnections such as those demonstrated by SIMNET, each entity updates state variable parameters and transmits the new values whenever the change in these parameters exceeds preset thresholds. Thus, the update of parameters occurs asynchronously within the simulation system. To reestablish a synchronous simulation environment within individual entities, Dead Reckoning algorithms are used to extrapolate the state variable parameters of all external entities to the same current time of the individual entity. For reliable simulations, the extrapolating algorithms must be powerful enough to compensate for latency caused by transmission delays between entities and the lag in updating state variable changes.

3.4 Design considerations

The above discussion, while informative, is inadequate for those wishing to design a simulator network. Designers need to know or to create additional details to make the operational concept discussed above, a reality. Everything which can be delineated should be specified during the design process. The design should be implemented and tested whenever possible. The implementation should be evaluated to establish acceptable performance criteria where none exist. It is critical to test a particular item to its performance limit, with good as well as bad data.

Early experiments with DIS show several areas where acceptable performance has not been quantified. Most areas are related to correlation or acceptable deviation from a particular baseline value, which is not addressed in any standard. Correlation is the degree to which a single parameter (or set of parameters) matches between two simulators. Correlation is typically related to differences in the internal representations of parameters between two simulators.

Currently, the most obvious area needing correlation support is the visual system. Additionally, internal representations of the earth, relative geometry between objects, relative geometry between objects and the earth, and internal location of other vehicles are areas of immediate concern. Isolated

experiments have revealed problems with the above areas. Solutions are under active investigation, but definitive answers have not yet been found.

It is anticipated that when the immediate problems noted above are solved, a new set will arrive. For example, the effects of different mathematical models, simulated systems, and integrated network performance (as contrasted to an operational situation) are areas where concerns will arise after the immediate problems are resolved.

3.5 Keeping things manageable

The above methodology seems straightforward. However, many predicaments arise which can cause the process to lose focus and become less structured. Some of these are described below, along with guidance on alleviating the situation.

3.5.1 Anticipating problems

One must become adept at anticipating problems. There is a potential for problems anytime there is a technically complex task where the participants may have multiple and differing objectives, or where a diverse group of individuals is involved. Such is the case in developing simulator networks, or for that matter, any complex or large system. To make this situation tractable, a leader must be chosen. The leader must anticipate that problems will arise and be prepared and empowered to resolve those problems quickly. Fast problem resolution is important for two reasons. First, conflict diverts the team from the task at hand. Second, more problems will arise during the development of the simulation network. Problem resolution techniques are dependent on the specific bindings between participants and the leader. The problems, though, must be addressed and resolved quickly.

3.5.2 Working out risk

For reasons similar to problem resolution, all parties involved in developing a simulator network must make a constant attempt to work out risk. Risk avoidance is primarily a technical matter but also can involve making sure qualified individuals are involved with the project and the iterative requirements<->prototyping process is convergent and not divergent.

3.5.3 Addressing/resolving problems head-on

Problems arise in research and development. Problems do not go away by themselves and unresolved problems will also bring new problems. Therefore, problems arising in developing simulation networks should be documented and resolved in an expedient manner. Documenting and tracking problem resolution is also critical.

3.5.4 Making decisions

The development process inherently provides that decisions must be made. Indecision cannot be allowed to fester too long because it will cause the requirements<->prototyping process to diverge. There are many decisions to be made by the participants developing a simulator network which must be made in a timely manner.

3.5.5 Allowing changes

Changes are also an integral part of the iterative design process and concurrent engineering. Changes must therefore be allowed and should be tracked and quantified. However, the number and impact of changes must decrease as the iterative development process progresses. These quantities should decrease with respect to calendar time to ensure design closure is achieved. If the quantities noted above do not decrease with time, requirements will be difficult to achieve. There is often an adverse perturbation near the end of an iteration cycle when a concept is implemented (step 4 of Section 3.2). This is normal, but the perturbations should grow smaller, not larger, with time.

3.5.6 Record keeping

The importance of timely record keeping cannot be overemphasized. All individuals on a design team should maintain a notebook in which they record decisions and other pertinent events. The project leader should publish timely records of decisions and actions to ensure a proper and accurate record of events is maintained.

An example of the preceding discussion can be found in Appendix A of this handbook. Also, in Section 10, a case study of simulator networking using the DIS protocols is described. A record keeping means called an "Actions and Decisions List" was used to keep the project on task, focused, and documented. The procedure records actions as events which

cannot be immediately resolved. Actions are assigned to an individual for disposition. Decisions are records of events which can be resolved immediately. Completed actions become decisions.

3.6 Components of simulator network interaction

There are many ways to characterize simulator networks. The particular method chosen here is logical and divides the development effort into regions corresponding to areas of technical specialization. The simulator network is divided into:

- The network proper,
- The simulators,
- The environment, and
- Scenarios and usage.

The reasons for these sharp distinctions are explained below.

3.6.1 The network

The network is the hardware and software mechanism which allows an entity to communicate with another entity. Therefore, the software and hardware components internal to a simulator, which allow it to communicate with other simulators, are part of the network, not the simulator.

Modern networks are extremely complex tools. Without employing a modular design approach, design and development of these systems would be an intractable problem. One requirement of such a modular approach is that all internal interfaces can and must be precisely and completely defined. The complexity also means that the external (user) interface must be as clearly specified.

A consequence of the complexity and subsequent standardization is that network specialists design networks, and others use them in their systems as components or as pre-defined tools. Few designers of networked simulator systems desire, or can afford, to develop their own network protocols and hardware. They purchase them and must then adhere to the interfaces as specified by the network designers if they expect to gain their advantages. The developers of the simulators themselves need only be concerned with designing their functionality up to the interface. Therefore users should clearly separate the network from the simulators.

3.6.2 The simulator

The simulator is the reason for the simulation network. Its purpose is the generation, display, and measurement of the behavior of the entities which are simulated.

A simulated entity may represent a single life form, a vehicle or weapons platform, a command post, a piece of terrain, or even a portion of a life form, such as the decisions and actions of a tank commander when he is carrying out the responsibilities of a tank platoon leader.

An entity need not necessarily occupy space in, nor consume the resources of, nor affect the simulated environment of a virtual world, although it may do any or all of these. Most entities probably will. Exceptions to occupiers, consumers, or affecters might be monitoring tools such as magic-carpets, map displays, passive radar displays, data-loggers, etc.

There is not necessarily a one-to-one relationship between simulators and entities. Multiple entities may be modeled on a single computer; multiple computers can be used to model a single entity, or multiple computers might be used to model multiple entities. An example of the latter might be a case in which one computer simulated the vehicle dynamics of all entities, another simulated the decisions made by all the drivers, and so on.

The simulator is constrained to be the hardware and software which together are used to define an internal representation of an entity in terms which are compatible with the user interface of the network. This means that the simulator has the responsibility to simulate behavior and to perform the calculations and actions only up to the point at which it can use the services defined by, and provided by, the network to make this behavior apparent to other simulators. Conversely, the simulator can expect to obtain information concerning the behavior generated by other simulators via the network. The data to be placed in the messages sent between computers to model or control the entity are generated by the simulator. This data must be provided to the network in the format specified for the network. This formatting process is considered part of the simulator.

3.6.3 The environment

The environment is the representation of the simulated world or the gaming areas in which entities operate and interact. The environment includes the space, the atmosphere, the earth, and the sea.

Most simulator networks have defined only the simulators and the network. The environment is separated out here for several reasons:

- In DIS a consistent environment is an essential element to achieving non-biased simulator interactions. With no correlation between the environments used in two simulators, any interaction between the two would be accidental and probably meaningless. The level of meaningful interaction is roughly proportional to the percentage of correlation. In DIS it is left to each simulator to define its environment. It is, therefore, a task of DIS designers to manage environmental consistency.

- Like a network, the environment is often a separately procured item (e.g., a visual system and its specially constructed databases).

- In some networked simulations, such as the joint modeling and simulation system (JMASS) [JMASS,1991a] [JMASS,1992a] [JMASS,1992b] [JMASS,1992c] [JMASS,1992d] the environment is centrally managed by dedicated computer resources.

  The environment is a common transmission medium for the simulators in JMASS. However, in DIS networks, the environment is separately stored by each simulator. Separate storage of the environment makes the message passing portion of the network simulator system simpler than if a central environment is used. However, separate storage also provides an opportunity for varying levels of consistency between simulators on the network. The result of separate environment storage can result in inconsistent operation between simulators, if the environments are not consistent. Extreme care must be given to environmental consistency in critical areas (as determined by the requirements process) of the simulator network to avoid anomalies in individual simulator behavior.

3.6.4 The scenario and usage

The <u>scenario/usage</u> provides some notion as to how entities are expected to interact in the environment. The scenario is a collection of subsets of possible environments, entities, initial conditions, missions, and assumptions about preceding conditions. Usage describes the purpose to which the simulation is being put. Examples of usage might be training, analysis, system design, or combat development.

IST emphasizes the importance of considering the scenario/usage portion of the simulator network because of the unique skills required of individuals working in this area (e.g., educational specialists or military users).

Scenarios are an essential component in the systems design of an effective DIS network. Scenarios provide meaning, purpose, and structure to the use of simulation. Simulator networks may be designed to support training, acquisition, test and evaluation (T&E), analysis or other (non-defense). Each of these areas of simulator usage has its unique scenario design requirements.

The scenario is necessarily constrained to the capabilities and limitations of the network, the individual simulators on the network, and the environment available to the network. The capabilities of the networked simulators determine the ability of the scenario to support the intended use. The simulator system can be described as the media with the scenario being the message. The user must determine if the media (the networked simulator) can carry the message (the scenario).

3.6.5 Interaction of the components

When integrated, the four areas form a simulation network system. A change in one of these areas often affects another area. Figure 4 illustrates the interaction. Lines on the figure show typical impacts of changes in one area on the other areas. It is very important that these four areas evolve so that no one area unduly constrains another. To achieve this goal it is recommended, as the design iteration process occurs and various aspects of the design are defined, at least two areas remain at equal levels of flexibility. Having the design evolve in this manner ensures that constraints due to design choices made in one area can be handled by redesign in another area.

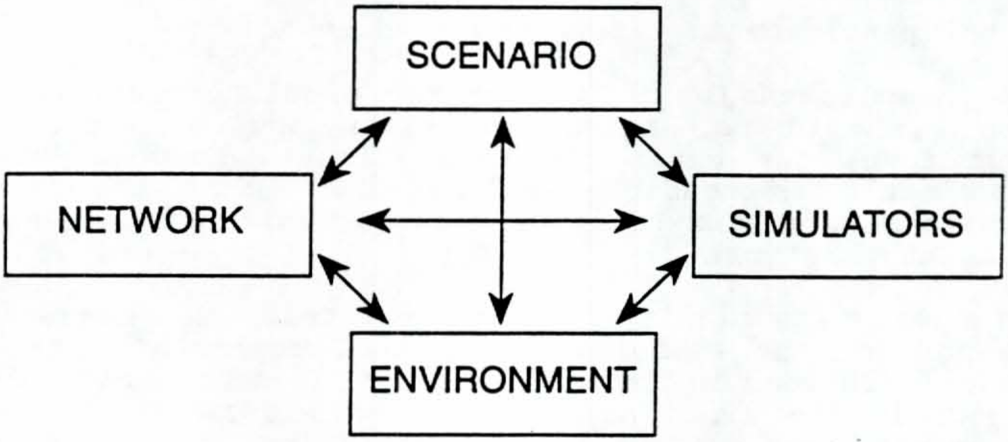


Figure 4. Interaction of Simulation Components

3.7 Organizational participation in simulation networks

Many types of organizations can be expected to participate in developing and operating simulation networks. Organizations include government, industry, and academia. Their roles can include development, operations, or utilization of the simulation network. Each organization comes to the simulation network project ("project" can be developmental, operational, or utilization) with different needs and biases. Many of these needs and biases are not communicated to the simulation network design team. It is important to hypothesize and document these needs to assure a high probability of success in the final system.

3.7.1 Motivating factors

It is important to recognize the motivating factors of those participating in or supporting the development of a simulator network. Not being aware of their motivations or not creating an overall set of motivations (i.e., goals) can be a recipe for disaster in achieving the goals of the simulator network. These motivations are not always apparent. However, it is important to recognize the motivating factors and use them to make the simulator network a success for all of those involved.

Coupled with the motivating factors are the influences or demands one can place on those involved in creating, operating, or using the simulator network. Formal arrangements are best because, theoretically, everything anyone will do is known. However, no formal arrangement can anticipate the unexpected or be all encompassing.

3.7.2 What participants can be expected to do

Clear goals should be set for the simulator network. These goals should be stated but often are not communicated. Therefore, the goals and motivations should be stated as succinctly as possible but in a way that recognizes and provides some flexibility for the organizations creating the simulator network.

An example may clarify the above points. A demonstration held as part of the 1992 I/ITSEC is the subject of a case study described later in this document. This demonstration was the first of its kind for DIS and the P2851 common data base programs. The motivations for participating in this project included:

- Demonstration of the utility of networking simulators and of the feasibility of new technologies in order to gain support for current efforts,
- To increase the chances for future contract awards for similar technology,
- To satisfy existing contract requirements, and
- To seek continued support from sponsoring organizations.

Each of these motivations brings its unique set of requirements to a demonstration. The project leadership must be sensitive to these motivating factors.

3.7.3 What the participants will probably not do

Participants in simulator networks will not take undo financial or programmatic risks. Financial risks can be determined on an individual basis and can be remedied by the participant withdrawing from a simulator network project or by the participant receiving more funds from his or her sponsor.

Programmatic risks are much more difficult for external parties to ascertain and much more difficult to remedy than financial risk. Systems designers must be watchful for signs of programmatic risks.

Programmatic risks arise from the public nature of the simulation network. Previously, organizations developed simulations for training, for acquisition, and so on. The organization developing the simulation had complete control over the entire simulation environment. Little insight was

available into the simulator's internal operation or the synthetic environment in which the simulator operated. Public networks change the rules. Organizations no longer have control of the environment in which their simulator operates. Therefore embarrassing situations can arise. Designers must be sensitive to the fact that only those who need this knowledge should have access to the network simulation environment as it develops and as different participants are added to the network.

Other programmatic risks can arise due to procurement issues. Simulation can be a powerful tool of persuasion. Therefore, the environment created by a network of simulators must be above reproach. The environment should be subject to public scrutiny if it is to be used in any form of evaluation. Open scrutiny of the environment will minimize programmatic risks.

3.7.4 Problems with proprietary data

Proprietary data is that to which one organization has exclusive rights. Simulation networks must be designed not to compromise this data. Use of the DIS protocols themselves does not divulge proprietary data. However, the process of achieving interoperability can broach into proprietary matters. Interoperability implies that some knowledge, in excess of that sent over the network, is known to everyone on the network. For example, military users have certain expectations of the appearance and performance of an M-1 tank. The network must provide a consistent representation of the tank for the task to be accomplished by the network. Protocols do not provide such information. Therefore a common set of expectations should be developed and provided to all participants.

Commonality does not require that all simulators be the same, but it does require that an analysis of the uses of the simulation network be conducted and that the areas which require commonality remain common. External tests can be developed which assess simulator commonality in relevant areas.

3.8 The use of standards

Technology usually develops in a predictable sequence. Research leads to prototypes, prototypes are used for demonstrations and as a basis for development items, and development items are used to refine techniques and performance prior to production.

The timing and methods of transitioning between phases is not always apparent. The recognition of milestones for transitions between phases is further complicated by the fact that the process described above, and earlier in this document are repetitive.

Standards can be used as a means to transition between development phases. Standards are appropriate where it is desired to stabilize a technology or where an ordered set of product improvements and/or development is indicated. Ada (MIL-STD-1815) is an example where the former is true, while the Avionics Data Bus (MIL-STD-1553) is an example of the latter. The migration from SIMNET to DIS standards is an example where both motivations noted above have been forcing functions to the migration. The following discussion of standards is specifically oriented to DIS.

3.8.1 Benefits of using standards

DIS considers four aspects of simulator networking as separable standards activities. The first activity is related to creating a consistent set of application level messages or Protocol Data Units (PDUs) between simulators. A standard is being developed which addresses these PDUs. The second activity is related to a standard called the "Communications Architecture for Distributed Interactive Simulation" (CADIS) [IST-PD-92-2], which specifies the passing of messages between simulators. The third activity relates to what simulators do with the PDU data. This standard involves such matters as correlation. Its purpose is to define standard methods for consistency in data utilization. The final standard involves the use of feedback after action reviews and network exercise control.

The latter two standards are in the early stages of development. Therefore, specific separation of functionality has not yet been defined. The CADIS standard exists in draft form. The application level PDU standard has been accepted by the IEEE and is known as P1278 [IEEE,1993]. The following discussion provides additional information on the DIS set of standards.

DIS will take advantage of currently installed and future simulations manufactured by different organizations. Consequently, a means must be found for assuring interoperability between dissimilar simulations. The first step in achieving this interoperability is to develop a communications protocol. There must be an agreed upon set of messages that communicate between host computers the states of simulated and real entities and their interactions. This

information is communicated in the form of an application level PDU.

Using the work of SIMNET as a baseline and considering recommendations made in meetings and position papers, a first draft of a military standard was developed which describes the form and types of messages to be exchanged between simulated entities in a DIS. This draft standard was distributed to industry and government for review and comment in June 1990. Subsequent revisions [IST-PD-91-1] led to P1278.

3.8.2 Drawbacks to the use of standards

A standard is often viewed in a context larger than its own scope. The result is that the user of a standard expects it to contain information or guidance that is not explicitly contained in the standard. In addition, the standard often leads one to a conclusion that is not directly supportable by the standard. An example will illustrate this point.

Ada is described by MIL-STD-1815. The expectation one receives from the Ada standard is that a mature syntax is available for software development of mission critical DoD software. In point of fact, an extremely limited product base of Ada development was available when the Ada standard was released. In addition, the language's ability to support mission critical applications was very much tied to the hardware environment, which was not mentioned in the standard.

The DIS standards must be used in a development context instead of a production context. The standards are quite extensive with respect to application; however, they do not describe the DIS environment in an unambiguous manner [IST-TR-92-17]. Ambiguity tends to keep the potential domain of application large. However, ambiguity causes problems with those trying to make an integrated system work. Ambiguity results in participants meeting periodically to identify and resolve the ambiguity. The act of meeting periodically is necessary to resolve ambiguity in the DIS standards.

Standards must also be subjected to external scrutiny and testing to determine the robustness of the document. Only limited testing has occurred [IST-TR-93-04] on the DIS standards.

3.9 Requirements

The requirements for simulation networks dictate their design and ultimate utilization. The previous statement, while obvious, is very difficult to achieve because, traditionally,

requirements and deliverable technology seldom match. Requirements are either poorly stated, not entirely described, or stated in a manner that exceed technical, cost, or schedule guidelines. Technical capabilities suffer from the same shortcomings as requirements. For these reasons, this handbook recommends an iterative design process where requirements and technologies merge instead of diverge.

The requirements generation and development processes also suffer from differences in individual backgrounds, terminologies, and goals. The requirements process starts with a user's perspective. Users state their needs in terms familiar to other users. The reasons are to gain support for the simulation networks from the groups who will ultimately use the system. Also, job requirements often lead users and developers to different orientations for the ultimate product. Developers are often biased by the need to innovate and improve on existing designs. The need to innovate and improve are part of the Total Quality Management principles espoused by W.T. Deming [DEMING, 1982]. Problems often arise, though, when the innovation and the improvement are part of a specific development project for a user. Therefore, innovation must be kept separate from prototyping. Entry points for innovation should be planned for in advance. These matters must be communicated between user and developer.

The requirements generation process needs an interpreter to put the requirements in terms to which the technical community can respond. The iterative process described previously, coupled with frequent demonstrations, is a useful tool to ensure that the requirements generation process is being properly communicated to interested parties.

3.10 The effect of excess capacity

Excess capacity is extremely important in the development of simulator networks. Excess capacity is necessary in all four areas of the simulator network: the network, the simulator, the environment, and the scenario/usage. The reason is that simulator networks tend to grow. For example, users, realizing the benefits of simulator networking, in contrast to individual simulations, will demand more networking resources. Even demonstrations of simulator networks cause expectations to grow for the next set of demonstrations. Another reason is that excess capacity helps level the capabilities of particular required aspects of the network environment.

Excess capacity must be built into each of the four areas. The simulator can have excess capacity by having additional computing resources available to respond to additional simulation needs. Such needs can arise when expansion of the

operating environment of the simulator is necessary. Expansion of the operational range may be required to evaluate an extended altitude capability for a new aircraft. Also, excess capacity in the environment is necessary to provide for consistent representation of the environment, for example, between visual systems or to expand the operational range of the simulated entity. Excess capacity in the network is required to provide for additional entities or connection to other networks. Further, excess capacity in the scenario/usage is required to explore new strategies for utilizing simulator networks.

3.11 The importance of baselining

There are two aspects of baselining relevant to simulation networks. One aspect involves the use of standards as a tool to baseline relevant technologies. The second aspect involves the simulation network design process. Baselining using standards is addressed elsewhere in the handbook.

It is critical to baseline the design of the simulation network as it evolves. A baseline allows others to understand the state of a system. Creating a baseline is similar to making a record or taking a photograph. Baselines must be created on a definitive foundation. Time, performance parameters, or requirements are all suitable for creating a baseline. The baseline becomes static and controlled and typically includes statements such as, "At the time this standard was created the following performance parameters were in place ..." Its creation is an easy task. It entails identifying all of the relevant parameters of a system and specifying the values of those parameters. One should attempt to identify all of the parameters; however, it is all right if some are unaccounted for. Unaccounted parameters can be identified and recorded as an update to the baseline.

3.12 The importance of iterating

Iteration provides a mechanism to refine the simulation network design as more information becomes known. Additional information comes about from studies or demonstrations. Iteration is necessary because improvements can always be made in systems per the principles of Total Quality Management. The field of simulation networking is new; therefore, iteration should be planned in the development process.

3.13 The interplay between components

The interplay between components is extremely critical. A decision made in one of the four areas impacts at least one of the other three. Therefore, a balanced design is critical to ensure consistent use of available resources within the various areas.

An example illustrates the interplay. During the development of the simulator network for I/ITSEC, early analysis showed the network had bandwidth limitations due to the inability of some network interfaces to receive data at the anticipated speed and volume. The result was a limitation on the number of simulators which could simultaneously occupy the network. However, further examination showed additional limitations imposed by the environment and simulator which further restricted the number of simulators able to be active on the network. These restrictions required the scenarios to be designed to accommodate the simulator limitations.

4 Networks

Networks are defined for the purposes of this handbook as a set of interconnected entities. The interconnection is further restricted to computers and voice communications. Within computer networks, a distinction will be made between local area networks (LANs), extended local area networks (ELANs), and wide area networks (WANs). The distinction is made clear in Figure 5. IST has specifically excluded networks which may include video transmission because such networks are experimental and untried in a simulation environment. Voice and computing can use the same network, in theory. However, the more common method in simulation is to use separate voice and data channels for ease of encoding and decoding.

The DIS standards are designed to address two aspects of networking simulators:

- What simulator data is transmitted between network nodes? and
- How is the simulator data to be conveyed between network nodes?

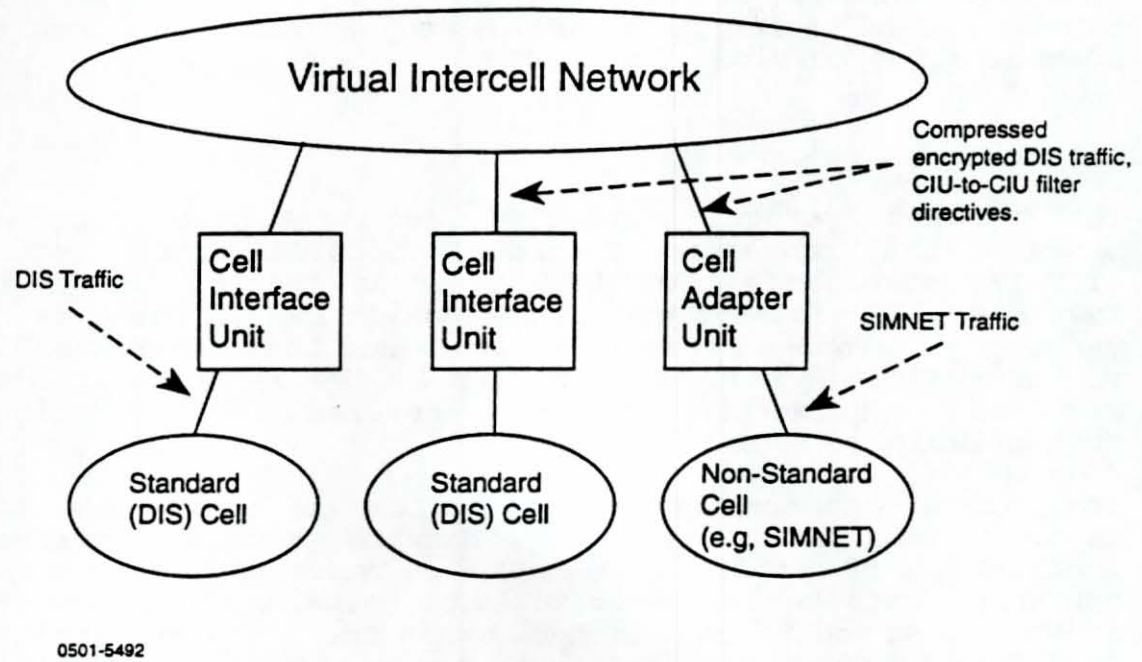


Figure 5. ADST Architecture DIAGRAM [ADST,1992-2]

The standard does not address voice networks or the specific distinctions between LANs, ELANS, and WANs. The above areas, therefore, must be specifically designed by participants wishing to create a simulator network. The following sections will provide some design guidelines and alternatives for areas which are not singularly defined in standards.

4.1 Stack layouts

To facilitate the interoperability of dissimilar simulations and to reduce cost, industry communication standards are being adopted to maximize the use of commercial-off-the-shelf (COTS) products and to maximize the base of practical technical knowledge. There are two sets of industry standards from which the simulation community can choose COTS products: the Internet Protocol suite, and the Open Systems Interconnection (OSI) model. The Communication Architecture and Security Subgroup (CASS) of the DIS workshops are recommending the use of Internet and OSI protocols.

Using industry communication standards can reduce cost and facilitate interoperability; however, they are not required to build simulation networks. Simulations can also be networked using proprietary protocols. In fact, the predecessor to DIS used a custom transaction protocol called Association Protocol

(AP) for reasons of reliability. AP was combined with Ethernet (and later IEEE 802.3) to provide the required communication services for SIMNET.

4.1.1 Internet Protocol Suite

The Internet Protocol Suite (IPS) is a family of protocols based on the Transaction Control Protocol/Internet Protocol (TCP/IP) standards. The IPS standards started in the mid 1970's and development continues today. Due to their twenty years of development, these protocols and their corresponding products are very mature. The IPS is the de facto standard for computer networking and boasts numerous implementations, most notably, the global Internet[1].

The Internet communication architecture is based on a four layer model (see Figure 6): Network Access, Internet, Transport, and Application. The *network access layer* is concerned with the exchange of data between a host and the network to which it is attached. When two hosts are attached to different networks, procedures are needed to allow data to traverse the multiple networks. This is a function of the *Internet layer*. The *transport layer* provides mechanisms to ensure transmitted data arrives at the destination process and that the data arrives in the same order in which it was sent. The *application layer* contains those protocols needed to support various applications, such as file transfer. A more detailed explanation of the Internet architecture and protocols can be found in [STALLINGS,1987c], [IETF1989b], and [IETF1989a].

APPLICATION
TRANSPORT
INTERNET
NETWORK ACCESS

Figure 6: Internet Communication Architecture

The Internet standards are composed of a large number of protocols, not all of which are required by networked simulations. The protocol suite recommended for DIS by the

[1] The Internet is a network infrastructure that supports research, engineering, education, and commercial services. It is sponsored by a variety of federal agencies such as the National Science Foundation (NSF) and the Defense Advanced Research Projects Agency (DARPA).

CASS is shown in Figure 7. The rationale for selecting the protocol suite can be found in IST-CR-92-19 and [IST-CR-92-20].

Layer				
Application Layer	SNMP	Telnet	FTP	NTP
Transport Layer	TCP		UDP	
Internet Layer	IP			
Network Access Layer	Any Subnetwork			

Figure 7: Internet Protocol Suite for DIS

At the application layer, Simple Network Management Protocol (SNMP) and Telnet will be used to meet the network management service requirement. SNMP will provide network monitoring, while Telnet will be used to establish terminal sessions for remote debugging and network management. The File Transfer Protocol (FTP) will be used to satisfy the file transfer requirement by providing a bulk transfer service (i.e., retrieval of databases). The Network Time Protocol (NTP) will be used to meet the synchronization requirement.

At the transport layer, the architecture is based on the User Datagram Protocol (UDP) for unreliable (or datagram) service and the Transmission Control Protocol (TCP) for reliable data transfer. At the Internet layer, the architecture specifies the Internet Protocol (IP) for seamless local/global communication.

The architecture will successfully operate over any type of communication subnetwork environment that meets certain minimum performance requirements such as those defined by IEEE 802.3.

4.1.2 Open Systems Interconnection

The other option for protocol interoperability is to comply with the Government Open Systems Interconnection Profile (GOSIP) mandate which has been in effect since August 1990. GOSIP is the U.S. Government program for adoption of OSI standards across all federal agencies. DIS will benefit from the OSI/GOSIP architecture through reduced cost, increased interoperability (both nationally and internationally), and increased application level functionality. The DIS protocol standard was developed with the goal of using the GOSIP protocols. Unfortunately, GOSIP has not reached the level of

maturity of the IPS; consequently, many view GOSIP compliance as a long-term goal.

The OSI standards began publication in the mid 1980's. Based purely on the chronological age, the IPS base stack is more mature. However, many of the OSI protocols are based on their Internet predecessors; therefore, some OSI protocols gain stability from lessons learned from IPS experience. Product maturity is hard to measure, but due to the limited installed base of OSI products maturity is not to the level of the IPS.

The cost of OSI products is higher than that of the IPS for several reasons. First, the development of the IPS was funded in large part by federal agencies through research grants. Therefore, vendors did not have to spend their own money to mature the protocols and products. In contrast, OSI is being developed by industry. Consequently, the capital expended in the development of both the protocols and products is passed on to the customer.

Although OSI cannot boast implementations as numerous as IPS, OSI is slowly growing and is even being integrated into the global Internet. The National Science Foundation network (NSFnet) backbone has offered national CLNP[2] service since August 1990. There are approximately 25 regional networks which are part of this "OSI over the Internet" testbed, including: Energy Sciences network (ESnet), NASA network (NASAnet), Southeastern Universities Research Association network (SURAnet), and New England Academic and Research network (NEARnet). These regional networks route both Internet and OSI traffic. There is also a world X.400 (OSI electronic mail) backbone connecting the U.S., Europe, and the Pacific Rim. In addition, several new major government procurements specify OSI/GOSIP communication services. These procurements include the Department of the Treasury, the Department of Energy, and the Department of Agriculture. The Federal Aviation Administration (FAA) is also starting new OSI research projects.

The OSI communication architecture is based on a seven layer model (see Figure 8): physical, data link, network, transport, session, presentation, and application. The *physical layer* is concerned with transmitting raw bits over a communication channel. The main task of the *data link layer* is to take a raw transmission facility and transform it into a line that appears free of transmission errors. How packets are routed from source to destination is the responsibility of the *network layer*. The *transport layer* is an end-to-end layer which is concerned with ensuring that data arrives correctly

---

[2] CLNP is analogous to the Internet IP protocol.

(i.e., in order and without errors). The *session layer* allows users on different machines to establish sessions between themselves. The *presentation layer* is concerned with the syntax and semantics of the information transmitted. The *application layer* contains a variety of protocols, such as network management.

A more detailed explanation of the OSI architecture and protocols can be found in [STALLINGS,1987b], [ROSE,1990], and [TANENBAUM,1988].

APPLICATION
PRESENTATION
SESSION
TRANSPORT
NETWORK
DATA LINK
PHYSICAL

Figure 8: OSI Communication Architecture

Like the Internet standards, the OSI standards are composed of a large number of protocols, not all of which are required by networked simulations. The OSI protocol suite recommended for DIS by the CASS is shown in Figure 9. The rationale for selecting this protocol suite can be found in IST-CR-92-19 and [IST-CR-92-20].

Application Layer	CMIP ¦ VTP ¦ FTAM
Presentation Layer	Skinny Stack
Session Layer	Skinny Stack
Transport Layer	TP4 ¦ CLNP
Network Layer	CLNP
Data Link Layer	Any Subnetwork
Physical Layer	Any Subnetwork

Figure 9: OSI Protocol Suite for DIS

At the application layer, the Common Management Information Protocol (CMIP) and Virtual Terminal Protocol (VTP) will be used to satisfy the network management requirement. CMIP provides network management and monitoring, and VTP will be used wherever terminal sessions are needed. The File Transfer Access and Management protocol (FTAM) will be used to satisfy the file transfer requirement by providing a bulk transfer service (i.e., retrieval of databases). The synchronization requirement is being developed within the OSI program of work.

The session and presentation layers will be implemented using the skinny stack approach described in [FURNISS,1992]. At the transport layer, the architecture is based on the Connectionless Transport Protocol (CLTP) for datagram service and the Class 4 Transport Protocol (TP4) for reliable data transfer. At the network layer, the architecture specifies the Connectionless Network Protocol (CLNP) for seamless local/global communication.

The architecture will successfully operate over any type of communication subnetwork environment that meets the minimum performance requirements mentioned before (i.e. IEEE802.3).

DIS will also need network and transport layer multicast protocols; this work is currently under development.

4.2 Protocol Data Units

In a simulation network, there must be a means to communicate between the simulators. The state and actions of individual simulators must be conveyed across the network for others to correctly depict them. DIS PDUs are the elements of data exchanged between simulators to provide the information required for interactive, real-time, and networked simulation. PDUs are defined internally through division into individual fields. Their specific layouts are documented in [IST-PD-91-1].

As previously discussed, DIS refers to an architectural approach in which a simulation is distributed across a number of independent and self-sufficient computers instead of being confined to one central computer. This leads to the requirement that information be sent across the network describing the states of the simulation entities. Upon receiving this information, computers can incorporate these state changes into their simulations.

Version 1.0 of the DIS PDU standard [IST-PD-91-1] lists ten application level PDUs. Other PDUs will be added as the standard matures. New PDUs will be incorporated in the next

draft standard (Version 2.0) [IST-CR-92-12]. The following is a brief description of each PDU listed in the version 1.0:

Entity State PDU - contains ground truth information about an entity being simulated. Information associated with the appearance and location of an entity is periodically sent over the network via this PDU.

Fire PDU - describes the type of munition fired, the location of the weapon from which it was fired, and the initial velocity of the munition. Also present is the target range used for the fire control system. This PDU is issued by an entity the moment it fires a weapon.

Detonation PDU - issued when the trajectory of a fired munition is terminated. The simulator issuing this PDU will inform other entities that it triggered the explosion of the munition or was hit by it, so they may produce the appropriate visual and aural effects and assess the damages.

Collision PDU - used to communicate information about a collision between two simulated entities or between a simulated entity and another object in the simulated world (such as a cultural feature).

Service Request PDU - issued when an entity requests a service from another. Resupply and repair are two types of defined services.

Resupply Offer PDU - used to communicate to a receiving entity the offer of supplies from a supplying entity. The PDU will contain the number of types of supplies that the supplier is able to provide, the supply types available, and the amount of each.

Resupply Received PDU - used to acknowledge the receipt of supplies by a receiving entity. This PDU will contain the number of types of supplies that the supplier was able to provide, the supply types available, and the amount of each taken by the receiver.

Resupply Cancel PDU - used to communicate the canceling of a resupply service provided through the logistics support. This PDU is issued at any time to cancel the resupply service by either the receiver or the supplier during resupply.

Repair Complete PDU - used by a repairing host computer to communicate the performance of a repair service for the entity which requested it. This PDU is issued by a repairing host computer upon completion of a repair service requested by the receiving entity in a service request PDU.

Repair Response PDU - used by a receiving entity to acknowledge the receipt of a repair complete PDU. This PDU is issued by the entity receiving repair service upon receipt of a repair complete PDU from the repairing host computer.

The PDUs listed above are the first set of PDUs standardized for DIS. Because the standard is evolving, many PDUs are still being added to the list. In the DIS PDU Draft Standard (Version 2.0), seventeen more PDUs have been added. Of the seventeen, twelve support simulation management.

The simulation management functions serve to establish entity/exercise management and data management for simulators participating in a DIS exercise. The following is a list of the new PDUs for simulation management functions (a detailed explanation of each PDU may be found in [IST-PD-91-1]).

Create Entity PDU - used to communicate information about the creation of a new entity for a DIS exercise. It establishes the identity of the new entity;

Remove Entity PDU - used to communicate the removal of an entity from a DIS exercise. It indicates to the receiving entity that it is being removed from the exercise;

Start/Resume PDU - used to communicate to a simulation entity that it will leave a stopped (frozen) state and begin participating in a simulation exercise;

Stop/Freeze PDU - used to indicate to a simulated entity that it will leave a simulating state and enter a stopped state;

Acknowledge PDU - used to acknowledge the receipt of the create entity PDU, a remove entity PDU, a start/resume PDU, or a stop/freeze PDU;

Action Request PDU - used to request that a specific action be performed by a simulated entity;

Action Response PDU - used by an entity to acknowledge the receipt of an action request PDU;

Data Query PDU - used to communicate a request for data from a simulated entity;

Set Data PDU - used to set or change certain parameters in an entity;

Data PDU - used by an entity in response to a data query PDU or a set data PDU. This PDU allows the entity to provide requested information in a data query PDU;

Event PDU - used to communicate the occurrence of a significant event in a managed entity; and

Message PDU - used to input a message into a data stream either for use as a comment, error or test message, or as a place holder in a sequentially stored exercise.

Two PDUs introduced to Version 2.0 support emission regeneration in a DIS exercise. These are as follows:

Emission PDU - used to communicate active EW, acoustic emissions, and active countermeasures; and

Laser PDU - used to communicate information for lasing functions in support of a laser-guided weapon engagement.

The following three PDUs in Version 2.0 support the simulation of radio communications in DIS, which includes both audio and data transmission by radio:

Transmitter PDU - used to communicate the state of a particular radio transmitter;

Signal PDU - used to convey the audio or digital data carried by the simulated radio transmission; and

Receiver PDU - used to communicate the state of a particular radio receiver.

In preparing a simulation network, caution should be taken for those using DIS from several points of view. First, those wishing to conduct a DIS exercise should decide in advance what PDUs, and what portions of PDUs selected, will be used. For example, if the goal of the simulation network is only to have a demonstration of DIS, most of the scenarios may be described with only the first four PDUs: entity state, fire, detonation and collision PDUs. Second, unambiguous meanings must be agreed to for each PDU field. Third, caution should be taken in development due to the evolving state of DIS, as can be seen by the number of new PDUs proposed in Version 2.0.

The specific meanings agreed to for a given time may make future interoperability impractical.

4.3 Network topologies

The term "topology" refers to the way in which end systems (i.e., simulators) of a network are interconnected.

4.3.1 Local area networks

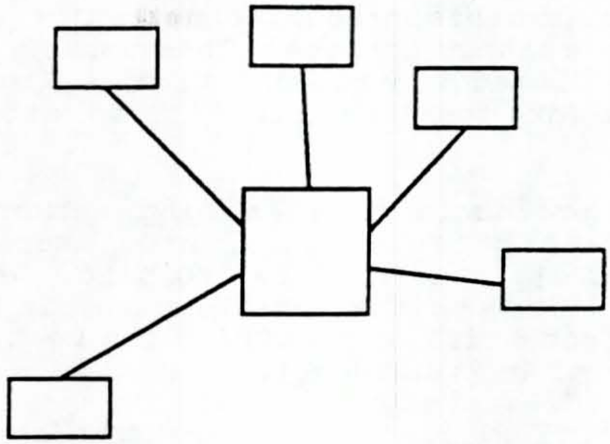
A LAN (local area network) is a communications network that provides interconnection of a variety of data communication devices within a small geographical area. Typical characteristics of LANs include: high data rates (0.1 to 100 Mbps), short distances (0.1 to 25 km), and low error rates (10^{-8} to 10^{-11} bps). LANs can carry not only data, but voice, video, and graphics.

There are four commonly used LAN topologies: star, ring, bus, and tree. The choice of topology depends on a variety of factors, including reliability, expandability, and performance. For more information on LANs, see [STALLINGS,1987a].

4.3.1.1 Star

In a star configuration, each end system is connected by a point-to-point link to a common central switch (see Figure 10). This topology exhibits a centralized communications control strategy.

When the star topology is combined with the bus topology, using a repeater as the central switch in the network, lower layer protocols like Ethernet 2.0 or IEEE 802.3 are used for data delivery.

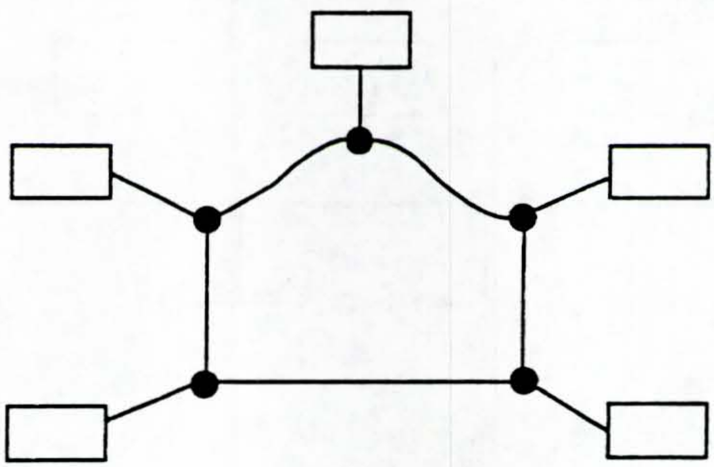


0482-5391

Figure 10: Star Topology

4.3.1.2 Ring

The ring topology uses a set of repeaters to join point-to-point links in a closed loop (see Figure 11). Hence, each repeater participates in two links. A repeater is a device which is capable of receiving data on one link and transmitting it, bit by bit, on the other link as fast as it is received. The links are unidirectional; that is, data are transmitted in one direction only.



C482-5392

Figure 11: Ring Network

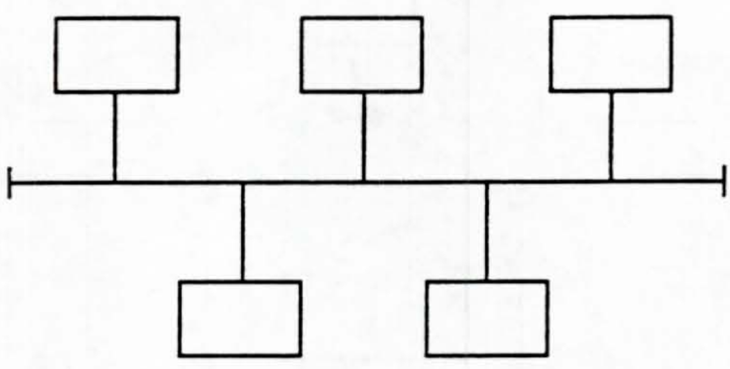
In ring networks, multiple computers share the ring. Therefore, control is needed to determine at what time each computer may transmit packets. This usually is done with some form of distributed control algorithm. Ring networks can be single cable or double cable. The latter provides more reliability.

Lower layer protocols used in ring networks include Token Ring, specified by IEEE 802.5, and Fiber Data Distributed Interface (FDDI), specified by ISO 9314. With FDDI, optical fiber is used between the repeaters in the ring. Hence, the ring has the potential of providing the best throughput of any topology (as high as 100Mbps).

There are practical limitations in terms of the number of end systems that can be connected in a ring, however. Single cable rings can have reliability problems; a single link or repeater failure can disable the entire network. Double cables, as used in FDDI networks, add reliability by using the backup cable when links go down or repeaters fail.

4.3.1.3 Bus and tree

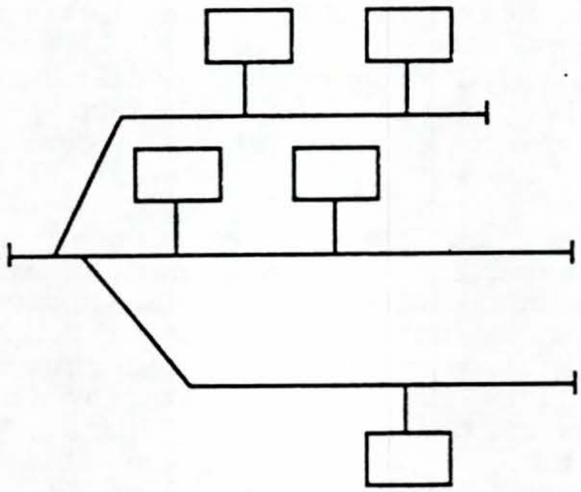
With the bus topology, the network is simply the transmission medium. There are no switches or repeaters (see Figure 12). All end systems attach directly to a linear transmission medium, through appropriate hardware. A transmission from any end system propagates the length of the medium and can be received by all other end systems. This is also known as broadcast medium.



0482-5393

Figure 12: Bus Network

The tree topology is a generalization of the bus topology (see Figure 13). The transmission medium is a branching cable with no closed loops. Like the bus topology, any transmission from one end system can be received by all other end systems.



0482-5394

Figure 13: Tree Network

Lower layer protocols used in these topologies include: Ethernet, Carrier Sense Multiple Access with Collision Detection (CSMA/CD) as specified by IEEE 802.3, Token Bus as specified by IEEE 802.4, and a non-standard protocol called SCRAMNET.

The bus and tree topologies are flexible in the number of devices they can handle, as well as in their data rates and data types. High bandwidth is achievable (on the order of 10Mbps)[3].

4.3.2 Wide area networks

A WAN (wide area network) is the interconnection of two or more geographically separated networks. For example, when two or more LANs are connected over phone lines or leased lines they then become a WAN (also called a "long haul network"). There are three types of WANs: Public Data Networks (PDN), for which there are packet-switched and circuit-switched networks;

---

[3] However, current research is applying the FDDI protocol to coaxial cable (and even twisted pair) networks to obtain 100Mbps transmission speeds.

Integrated Services Digital Networks (ISDN); and private networks.

4.3.2.1 Public data networks

A Public Data Network (PDN) is a network established and operated by some authority (e.g., AT&T) specifically for the public transmission of data. Standards used in PDNs are internationally agreed to and are accepted by the International Telephone and Telegraph Consultative Committee (CCITT)[4].

In circuit-switched PDNs, each connection results in a physical communication channel being set up through the network. This connection is then used exclusively by the two subscribers for the duration of the call. While the circuit-switched connection provides a fixed data rate channel, the subscribers must go through lengthy connection set-up procedures prior to transmitting data. Therefore, when transmitting data, a connection is established and kept open for the duration of the transaction. Because simulation exercises may last hours or days, this alternative can be very costly.

Packet-switched PDNs allow subscribers to operate at different data rates because the rate at which data is passed through the two interfaces to the network is separately regulated by each subscriber's equipment. In contrast to circuit-switched networks, data to be transmitted in a packet-switched network is assembled into packets with source and destination network addresses. Data are then forwarded on the appropriate links at the maximum available bit rate using routing directories. This mode of operation is also known as "packet store-and-forward."

ISDNs are PDNs which have the capability to handle not only voice communications but also data communications, concurrently if desired. This is very useful for simulation as exercises require both data and voice services.

While PDNs are advantageous from the point of view of ease and flexibility of network configurations, their benefits are offset by high tariff rates. A more detailed explanation of WANs can be found in [HALSALL,1992].

---

[4] All OSI standards are also CCITT standards.

4.3.2.2 Private networks

An alternative to PDNs are private networks which are installed and managed by private corporations, universities, and so on. For simulation, one such network is the Defense Simulation Internet (DSI). DSI is being developed by the DARPA and the Defense Information Systems Agency (DISA) with the support of the Defense Modeling and Simulation Office (DMSO).

DSI will be an integrated, wideband, wide area network targeted at supporting the modeling and simulation community, transitioning from a testbed/operational network to the Defense Information System Network (DISN). DSI provides a reserved bandwidth and guaranteed service and will be upgraded with emerging commercial standards. Currently it supports Internet standards and protocols and is being upgraded to support OSI/GOSIP. Installed sites include DoD and research facilities. Accessibility to DSI is not readily available to industry.

4.4 Selecting the stack and topology

As has been discussed in previous sections, there is a variety of protocol stacks and network topologies that can be selected when setting up networked simulations. The selection should be determined by a trade-off study considering time, money, expertise, performance, and expandability.

Once the protocol stack and topology have been selected, the network will evolve through three phases: development, test and evaluation, and operation. Development considers the actual development of the software and hardware required to construct the protocol stack and topology. Once the network has been developed, the simulators must be integrated and the entire system tested and evaluated. The operation phase considers aspects such as maintaining the networked simulators through monitoring and management.

4.4.1 Development

Choosing to build or buy the communication protocol stack is a decision dependent on many factors such as cost, time, and flexibility. A custom installation of a protocol stack can be expensive depending on the protocols selected and the implementation experience of the personnel. Some protocols, such as datagram protocols, are very simple and straight forward, whereas a multicast or voice protocol can be very complex. If personnel have no experience in implementing

communication protocols, even simple straight forward ones can be time consuming. Basic communication protocols from both the Internet and OSI standards are commercially available from most vendors at little to no cost with the purchase of the computer.

There are equally good reasons to build custom installations of protocol stacks. In some cases, the cost of implementation is mitigated by the knowledge gained which can be then applied to future projects. Simply buying an implementation would give no useful insights into protocol issues. With a custom implementation, the protocol stack can be designed to allow simple changes among a variety of protocols. Performance improvements can often be achieved with custom implementations as compared with a purchased protocol stack. IST has built a custom implementation which can support various combinations of protocols [IST-TR-90-15].

Choosing the network topology depends on several factors. These include expandability, reliability, performance, and cost. For LANs, the ring has the potential of providing the best throughput of any topology (as high as 100Mbps for FDDI). There are practical limitations in terms of the number of end systems that can be connected in a ring, however.

The bus/tree topologies are flexible in the number of devices they can handle, as well as the data rates and data types. High bandwidth is achievable (on the order of 10Mbps and increasing). Each topology has a degree of reliability but is still subject to failures.

When choosing a WAN, a driving factor is cost. A study must be performed to determine the type of traffic (voice and/or data), traffic characteristics (frequency of bursts, peak usage, etc.), frequency of WAN usage, degree of reliability, and equipment required to connect to WAN. Upon determining these factors, a trade-off analysis will result in the best possible choice of WAN technology.

4.4.2 Test and evaluation

The protocol stack and network must be integrated using a systematic approach. First, the network must be installed with each segment tested thoroughly using multimeters and network analyzers. When the network is fully established, network tests should be conducted to ensure network integrity. If problems are encountered, segments of the network must be isolated while faults are uncovered and corrected. Some internetworking devices, such as multiport repeaters and bridges provide these mechanisms.

When all faults have been corrected, simulators can be connected to the network. Prior to this, however, the simulator protocol stacks should have undergone some amount of testing to ensure all simulators have implemented addressing schemes (e.g., IP Class B) correctly, have used the same mode of transmission (e.g., broadcast), and have used the same application layer address (e.g., UDP port number). If even one of these issues is not implemented correctly, the simulator will not be able to send or receive data correctly.

4.4.3 Operation

Once the network and simulators have been successfully integrated, the network must continue to be monitored for faults and reliability for the duration of the operation. There are network management protocols which can be used to assist in the monitoring of network operations. These protocols will not monitor and report on the simulation itself. A separate simulation management protocol must be used.

A number of hardware devices can be used in addition to the network management software to monitor the network. These products are commercially available and include network analyzers and sniffers. Many of these devices can be programmed to track certain types of data (e.g., Ethernet addresses) and will give immediate feedback on traffic statistics (mean time between packet arrival, peak usage, etc). It is very important that the network topology be maintainable using the network analysis tools available. For example, if a lower layer protocol is selected and no network analysis tools exist which decode or monitor that protocol, then problems encountered due to the un-monitorable protocol will be hard to discover and correct.

In addition to the network and simulation management tools required to maintain the networked simulation, voice communications are also required. This can range from telephones, to walkie-talkies, to voice protocols running over the network. The type of voice communication will depend on the type of exercise being conducted and the resources available to the users.

A voice protocol would be optimum for the actual simulation in that the network is already established and the persons needing to be in contact are most probably operating the simulator on the network. However, a voice protocol is complex and not readily available from many vendors. Therefore, it is not advisable to use voice protocols.

In the case of tests or experiments, a voice channel such as telephone or walkie-talkie (distance permitting), will also be required to coordinate the experiment. As shown at I/ITSEC, walkie-talkies were an essential part of the command and control of the demonstration. Participants were located all over the convention room floor and were easily accessible using the voice network.

4.5 Network Interfaces

There are three levels of interfaces for networked simulators: the transmission medium, the Internetworking devices, and the actual simulators. The decision made at each level will have an impact on the performance of the simulator network.

4.5.1 Transmission Media

The transmission of an electrical signal requires the use of a transmission medium. In some cases this consists of a pair of wires; alternatives include a beam of light guided by a glass fiber and electromagnetic waves propagating through free space. The type of transmission mediumn selected is important because it determines the maximum number of bits that can be transmitted per second (bps). Another factor to consider is the propagation delay associated with each type.

The most commonly used media are twisted pair lines, coaxial cable, optical fiber, satellites, terrestrial microwave, and radio. Twisted pair lines have a good immunity to spurious noise signals, can operate over short or long distances, and have a maximum bit rate on the order of 1Mbps. Coaxial cable can be used with a number of different signal types, but typically 10Mbps over several hundred meters is the maximum rate achieved.

Optical fiber carries the transmitted information in the form of a fluctuating beam of light in a glass fiber. Light waves have a much wider bandwidth than electrical waves enabling optical fiber cable to achieve transmission rates of hundreds of Mbps. Satellite systems transmit data using electromagnetic waves through free space. A typical satellite channel has an extremely high bandwidth, on the order of 500Mbps.

Terrestrial microwave links are widely used to provide communication links when it is impractical or too expensive to install physical transmission media. For example, microwave links may be used across rivers or across town. Line-of-sight microwave communication can be used reliably over distances in excess of 50km. Low frequency radio transmission is also used

in place of fixed wire links over more modest distances using ground-based transmitters and receivers. An example of this is wireless-Ethernet.

4.5.2 Internetworking

When two or more networks are involved in an application, the mode of working between the systems is referred to as internetworking. The term internetwork (or internet) also refers to the composite network (e.g., LAN/WAN/LAN) being used. Each separate network (LAN or WAN) of the internet is called a subnetwork. The devices used for internetworking are commercially available and should be selected based on the network topology selected and the protocol standards used.

4.5.2.1 Repeaters

Repeaters extend the geographic coverage of a local area network. Networks are often split into two or more pieces due to maximum cable length restrictions on individual pieces (e.g., IEEE 802.3). Repeaters simply forward bits from one network to another, making the two networks look logically like one. These devices are not intelligent (no software); they blindly copy bits from one segment to the other without knowing what is being transmitted. Repeaters operate at the physical layer of the OSI reference model (see Figure 14) and may also change the medium type from thick to thin or to fiber optic, as long as the physical layer protocols are compatible on both sides of the device.

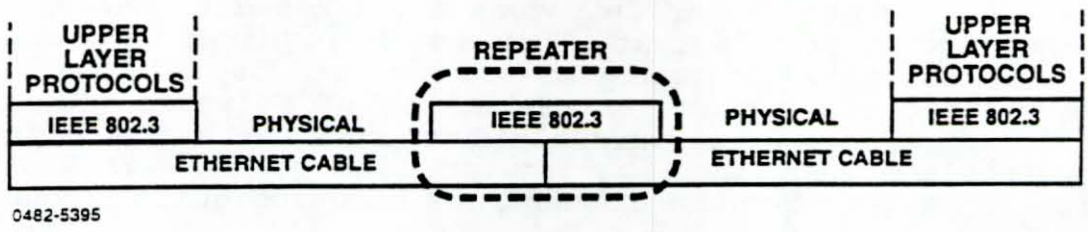


Figure 14: Repeater Connecting End Stations

4.5.2.2 Bridges

A bridge is used to connect two LANs at the media access control (MAC) sublayer of the data link layer (see Figure 15.) Bridges can be used to connect two homogeneous local networks or two networks which are using different data link layers but the same network layer. For example, a bridge could be used

to connect an Ethernet network to a Token Ring network, which both use IP as its network layer protocol. There are two types of bridges: local and remote. Local bridges connect two physically close networks while remote bridges connect two distant networks, commonly over T1 or T3 lines.

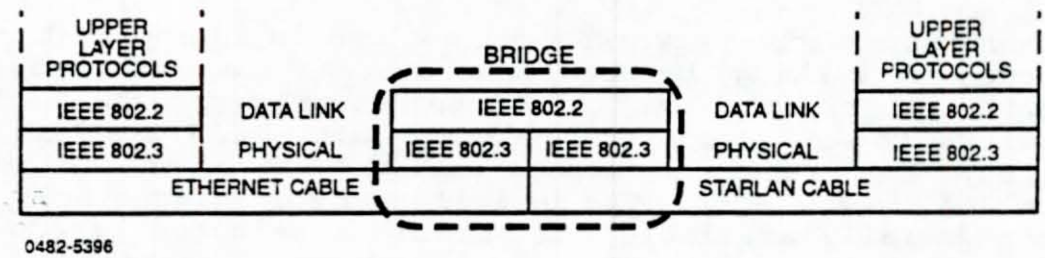


Figure 15: Bridge Connecting End Stations

Bridges are smart; they can be programmed to selectively copy frames for transmission across networks. They also provide improved overall reliability, availability, and serviceability of the total network. Bridges can increase performance of individual segments and enhance network security. However, the disadvantages of bridges are that they introduce an additional store-and-forward delay as compared with repeaters, and they can overload in high traffic periods due to the lack of flow control.

4.5.2.3 Routers

Routers function at the network layer in the OSI reference model (see Figure 16.) A router will choose the best route to sending packets within an internetwork based on the packet's final destination address. Routers are physical and data link layer independent devices but are protocol dependent devices. Therefore, routers support a variety of networks (Ethernet, FDDI, T1, etc.) concurrently but must be matched to the protocol in use at a particular site (i.e., TCP/IP, OSI, etc.). Multi-protocol routers are becoming quite common.

If a translation is performed from one protocol to another (e.g. from IP to CLNP) however, a processing delay will be encountered as compared to strictly routing from one IP network to another. Processing capabilities (i.e. data load) is device specific and can be determined from hardware/software specifications.

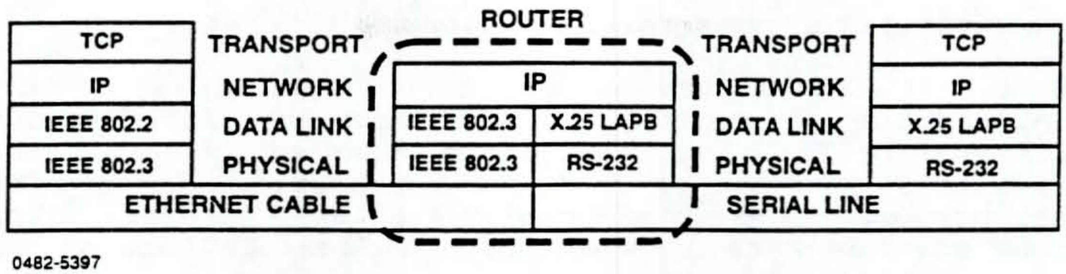


Figure 16: Router Connecting End Systems

4.5.2.4 Application gateways

A gateway is the most complex internetworking device, functioning up through all layers of the OSI reference model. Gateways interconnect networks with completely different communication architectures. They convert one protocol stack to another without modifying user data. For example, if two end systems wish to communicate but have different protocol stacks (e.g., one has OSI and the other has IPS) then an application gateway is required to translate from one protocol suite to the other (see Figure 17).

If a translation is performed from one protocol to another (e.g. from TCP/IP to OSI), however, a processing delay will be encountered as compared to strictly routing from one application network to another. Processing capabilities (i.e. data load) is device specific and can be determined from hardware/software specifications.

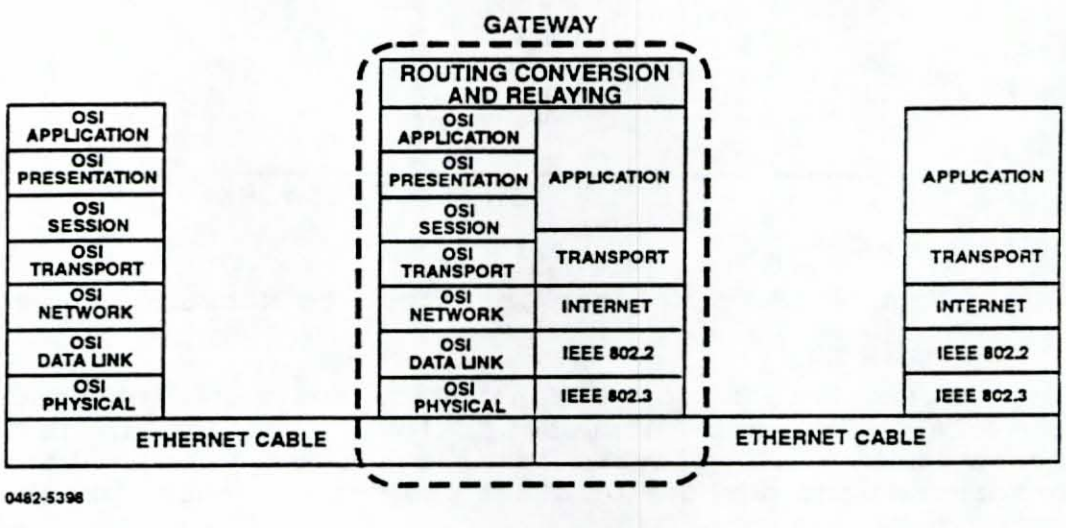


Figure 17: Application Gateway Connecting End Stations

4.5.3 Network interfaces for simulators

Most simulators use commercially available hardware to interface to a network. Most networks in existence today are Ethernet or IEEE 802.3 based and there are many commercially available Ethernet or IEEE 802.3 products. Early simulator networks used these commercially available hardware interfaces because they were inexpensive and flexible, and their data transmission rates were slow.

However, as the number of players and data transmission rates have increased, the utility of commercially available products has decreased. The decrease in utility results from either insufficient hardware resources to process the data or lack of positive control over the interface software. Alternatives have been developed to meet the growing performance requirements of simulator networks. One alternative separates the simulator from the network interface through special purpose hardware and/or software. Figure 18 depicts a typical arrangement.

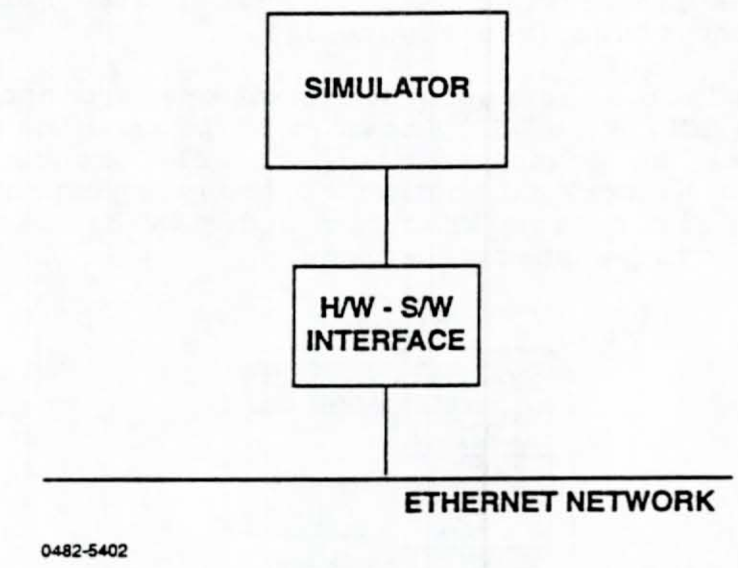


Figure 18. Simulator Interface to Network

Many manifestations of the hardware/software interface are possible. Two are discussed below. Caution is urged to ensure that all players are aware of the interfacing performance and methods of other players to assure predictable system performance.

4.5.3.1 Hardware interface

One method to interface the simulator to the internetwork uses a separate processor to handle the interface between the network and the simulator. The interface processor should have a multitasking operating system or pseudo multitasking operating system. The multitasking operating system allows data off-loading from the network, data storage, data insertion onto the network, and similar activities with the simulator to occur when necessary (i.e., asynchronously). Asynchronous operation is necessary because network traffic is asynchronous.

The interface processor serves several purposes. First, the interface processor provides a definitive separation between simulation processes and network processes. Such an arrangement is useful if either the network or simulator messages change. Second, an interface processor time buffers information between the asynchronous network and the normally synchronous simulation time cycles.

4.5.3.2 Filtering

Filtering is another useful technique to control the information flow between the simulator and the network. Simulator networks currently broadcast DIS PDUs. There can be more data available than is practical for the simulator to use. Therefore, some form of filtering is necessary.

There are several techniques to filter data. The goal is always to discard unnecessary data as quickly as possible, thereby avoiding needless processing or storage. There are two forms of filtering: by the sender and by the receiver. Filtering by the sender is known as "multicast transmission."

Multicast is a transmission mode in which a single message is sent to multiple network destinations, that is, one-to-many. Multicast selectively filters information thereby reducing the amount of PDU traffic a simulator must process; the filtering is performed by the sender of the data. For example, simulation entities are generally interested only in other simulation entities which are within some sphere of interest (e.g., visual range). Multicast will allow the sending simulator to send information about itself only to those entities in its visual range (also known as a "multicast group"). Another multicast group would be different multiple simultaneous exercises on the same network. Multicast groups can be based on the type of data determined to be a filtering mechanism.

Filtering by the receiver can be based on non-network data, based on PDU types, or based on fields within a PDU. Each of these methods is discussed below. Filtering methods, though, should be explicitly stated so that scenarios are properly structured and to ensure some level of filter consistency between players on the network.

A uniform filtering scheme between all simulators on the network is not necessary. It is necessary, though, that all simulators on the network know the filtering strategy being used by the other simulators so that appropriate scenario/utilization strategies can be developed.

Filtering based on non-network data is perfectly acceptable according to current standards for simulator networking. Parameters from other simulators can conceivably be available to another simulator through circuitous routes. Typical routes could be from a radar or visual simulation subsystem or through parameters internal to one simulator and not used by another simulator. For example, consider two simulators which at first glance are identical. However, one simulator does not simulate the effects of icing while the other simulator does. The first simulator, therefore, may discard certain environmental conditions which are not ignored by the other "identical" simulator. This de facto method of filtering by the first system can cause differences between the performance of the two "identical" simulators. Whether specific instances are of concern, or are significant, should be discussed by all of the players.

Filtering based on PDUs is another common method to lower the processing overhead of a simulator. Players operating on a simulator network should decide early in the development cycle which PDUs are necessary for them to accomplish their goals. Once these have been decided upon, each simulator network interface should filter based upon the agreed set of PDUs.

There are situations where non-standard data units must cross a network. These situations should be identified as early as possible so that players can accommodate such situations. For example, some computer generated forces systems use the network for infrequent control communication between the human operator and the computer generated entities. Other simulators need to be aware that non-standard traffic may be on the network in order for their systems to filter the data. Techniques such as point-to-point transmissions can be used to transmit non-standard data. A method to handle non-standard communications must be developed and agreed to among the various players of the simulator network.

Filter consistency between players is extremely important. An example will illustrate this point. Consider three simulated

players on a network. Player 1 is designed to filter out all non-visual data (e.g., non-network data), player 2 is designed to filter out all detonation data (e.g., PDU information), and player 3 is designed to filter out all entities more than 3 kilometers from player 3 (e.g., information contained within a PDU). One can quickly see that an untenable situation could arise if one player did not know how the other two players were filtering data.

4.6 Degree of network specificity

The degree to which the network should be specified is a gray area. While on one hand it can increase the degree of interoperability between simulators and increase performance, it can also limit the flexibility of the simulator network design. Therefore, careful consideration must be used in determining the correct balance.

4.6.1 Homogeneous and heterogeneous networks

There are two types of simulation LANs: homogeneous and heterogeneous. A homogeneous LAN is one in which all equipment (i.e., computing platforms, image generators [IGs], and simulation models) is provided by a single vendor. For example, SIMNET constitutes a homogeneous LAN. Within this environment, processing delays are usually constant and predictable across all simulators.

Conversely, a heterogeneous LAN is composed of dissimilar computing platforms (PCs, workstations, etc.), IGs (fixed versus dynamic priority) and simulation models. A heterogeneous environment introduces a range of operating speeds and performance to the network. One of the results of this heterogeneity is a reduction in the number of entities that can be simultaneously represented on the network. An example of a heterogeneous LAN is the 1992 I/ITSEC demonstration.

An analysis to determine the maximum number of entities that could be simultaneously represented on the I/ITSEC network identified five simulator processing constraints:

1) The bandwidth of the physical medium,

2) The rate at which the physical interface hardware can read/write information (in PDUs/sec),

3) The rate at which data can traverse the communication protocol stack (in PDUs/sec),

4) The number of entities each simulator can track, and

5) The number of dynamic coordinate systems each simulator's IG can manage.

From a survey of I/ITSEC demonstration participants, values for constraints 2 through 5 have a broad range as shown in Figure 19.

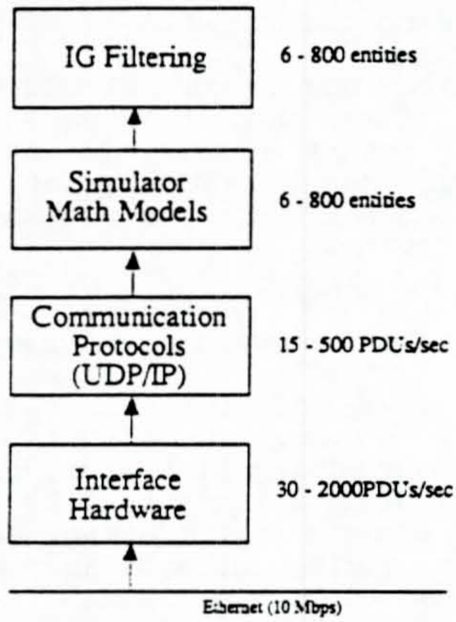


Figure 19. Processing Delays in Simulators

4.6.2 Maximums and minimums

To accommodate the largest number of entities and maximum performance in a simulator network, a homogeneous LAN/WAN should be used. Due to the predictable processing delays in homogeneous networks, the simulator network can be constructed to achieve optimum performance. A homogeneous network will also result in very few interoperability problems because all equipment is developed by the same vendor. However, homogeneous networks are highly inflexible with respect to design. It requires that all organizations purchase components from the same vendor and does not allow individual organizations to select networking components that best promote their simulator design.

In today's world, homogeneous simulation LAN/WANs are becoming rare. Therefore, a balance must be achieved in the degree of

network specificity. The goal of DIS is to provide an environment for homogeneous and heterogeneous LANs and WANs to interact in real time. In this environment, the individual simulator's ability to handle PDUs can be determined in one of two ways: either the minimum requirements are set and only those simulators which can meet the minimum requirements can participate, or the requirements are determined based on the highest common denominator of simulator performance. The first choice will result in limiting simulator participation, and the second choice will result in limiting simulator performance.

Heterogeneous simulator networks provide the maximum flexibility to organizations for designing and implementing their systems. The protocol stack and network topology can be selected based on an organization's requirements, as opposed to having to design to someone else's requirements. As previously discussed, there are commercial interfaces which can be purchased to translate between different protocols and topologies. As a general rule, the higher in the protocol stack the translation is performed the more performance degrades. For example, if the translation is between different physical layers, the performance penalty will be negligible compared to a translation performed by an application gateway. Therefore, to meet minimum performance requirements for real time simulation, components of the network must be specified.

The communication architecture for DIS standard was chosen to specify the protocol stack from the Network or Internetwork Layer up, allowing individual organizations to select the topology (and subsequently, the lower layer protocols) that best meet their specific needs.

5 Simulators

As previously defined in 4.6.2, a simulator is constrained to be the hardware and software, which together are used to define an internal representation of an entity in terms which are compatible with the user interface of the network. The following discussion is restricted to time stepped simulators.

5.1 Performance capabilities

Simulators normally represent a physical entity in the real world. Therefore, one can, theoretically, obtain data on an operational entity and use that data in the design of its simulator and, in so doing, relate simulated performance to an actual system.

Sometimes simulators represent entities which do not exist in the real world. Such situations arise with entities which may be undergoing design, which exist only in someone's imagination, or which represent a subcomponent of an entity. If the physical entity does not exist, the physical characteristics of the simulated entity must be enumerated by someone.

There are two approaches to measuring the performance of a simulator that are pertinent to designing simulator networks. One method of measuring performance may be by examining the internal algorithms and host hardware features when they are available to the evaluator. This situation arises normally when the network designer has a simulator which will be a node on the network.

A second approach is necessary when the internal representation of the simulator is not available. Such a situation arises when the designer is trying to integrate someone else's simulator onto the network.

In the first case, when the simulator's internal algorithms are known, two approaches are available to estimate its performance. One method is a time based analysis of the simulator. The other method is frequency based. There are advantages to each approach, and it is common to use frequency analysis before the simulator is built and time based analysis afterwards [NATC,1987], [FAA,1991]. Frequency domain analysis provides a broad overview of simulator performance as compared to the operational system, whereas time domain analysis provides detailed information on simulator and operational system performance over a narrow aspect of the system.

Frequency analysis cannot directly use the DIS standard. It should use Z-Transforms to analyze the performance of the simulator. The Z-Transforms are an advantageous analysis method because they account for the mathematical algorithms and the computer implementation of those algorithms. The Z-Transforms can be converted to the Laplace domain for comparison with the operational system and can be useful tools when the internal dynamic state of another entity (i.e., Dead Reckoned model) is to be compared to either the simulated entity or the operational system.

The results of Z-Transform analysis should be a Bode plot of phase and gain (expressed in dB = 10 log (output/input)) plotted against a frequency sweep. Margins should be established to ensure the dynamic performance of the simulated entity and its remote approximation should match the operational system. Experimentation with acceptable dynamic margins should occur which establish acceptable bands of performance for various simulator types. This topic is

currently being studied by researchers. Until margins are established, organizations developing a network of simulators must establish their own.

Time based analyses can take advantage of the DIS standard if time units are available. Time stamps are available from DIS. However, the units of time are relative to the sending simulator, not the receiving simulator. However, the time units are defined by DIS. Therefore, one needs two pieces of data to establish a relative basis for time. Network latency is not a factor when timestamps are analyzed. Time analyses consist of exciting the simulator through control inputs and observing the response of the simulator state variables over time.

DIS works by requiring each simulator to maintain an approximation of the location of other entities through the concept called "Dead Reckoning." Dead Reckoning is normally limited to a certain subgroup of participants. Subgrouping criteria is usually selected to be the distance from the simulated entity.

Dead Reckoning uses various algorithms to approximate the location of the vehicle. The algorithms are merely a set of numerical integration or predictor-corrector routines. Therefore, there are potentially an infinite number of routines which can be used to conduct Dead Reckoning. Currently, DIS recommends a consistent set of algorithms be used among all players on a network. Dead Reckoning is used to compute the position of remote entities and to compute when a state change PDU should be transmitted onto the network by any entity. In order to select an algorithm, a frequency analysis should be conducted to match characteristics of the Dead Reckoning algorithm with the characteristics of the various types of vehicles which will be Dead Reckoned. Also, a subjective analysis should be conducted which looks at the maneuvering characteristics of the vehicle to be Dead Reckoned. This matter will be explained below along with an explanation of thresholds for Dead Reckoning.

Dead Reckoning is used to conserve network bandwidth. PDUs are sent out only if the state information of an entity changes significantly. Between PDU transmissions, Dead Reckoning tracks the position of the remote entity based upon old state information. Dead Reckoning is used to track remote entities as well as the sending entity. Thresholds must be set which are used to determine when entity state data is to be sent and used instead of its Dead Reckoned state information. When thresholds are exceeded, a PDU is generated by the sending entity. The PDU is received by other simulators on the network and updates the remote entity position instead of using the Dead Reckoned position.

Thresholds must also account for latency which may be present in networks. Network latency is due to transmission time and the ability to get onto the network itself. Many networked simulator systems use threshold values of 10% of the entity length along any axis or 3° of rotation to trigger the generation of a new PDU. These values allow for an acceptable visual representation of slow moving vehicles (say under 150 kt.), but may exhibit jerky behavior for fast moving entities.

If a Z-transform analysis is conducted for all vehicles on the network, the highest performance entity (i.e., lowest gain and absolute value of phase shift) can be used to establish an upper bound for the Dead Reckoning algorithm (which can also be Z-transformed). Likewise, the lowest performing entity on the network can be used to establish the lower end of Dead Reckoning algorithms. Picking the higher performance dead-reckoning algorithm increases computational loading but presents a more accurate representation of the remote entity. A lower performance Dead Reckoning algorithm is computationally attractive but can introduce anomalies in visualization, collision, and so on. A good rule of thumb is to select a Dead Reckoning algorithm near the statistical mode of the performance of simulators on the network.

Thresholds usually contain a default time interval for generating new PDUs. SIMNET used five seconds and this value has been retained in DIS. The default value is used to guard against the possibility of missed packets and also as a backup to ensure deviations between the Dead Reckoned position and the actual entity position do not become divergent. The default time interval is adjustable. Therefore, if a simulated vehicle is expected to be maneuvering extensively or has a small threshold, the time interval between successive PDU transmissions will decrease, resulting in the ability to use simple Dead Reckoning routines. Thresholds should be adjusted to smaller values than those noted above to avoid visual anomalies.

5.2 Performance relationship to operational system

Normally, operational system data is available for baseline purposes. If so, the simulator should be excited in a manner similar to the operational system for comparison purposes. Many references are available for time response studies in simulators. [NATC,1981], [NATC,1987], and [FAA,1991] are the most useful for military and commercial vehicles, respectively. All are oriented to aircraft and flight simulators. Ground or sea vehicles methods can be gleaned from aircraft reference manuals.

A simpler method for comparing performance between the operational system and the simulator is to check the maximum performance characteristics, of interest (e.g., maximum velocity), at three different conditions (e.g., at different altitudes or weights). The maximum performance characteristics should match the operational system to within approximately +5%.

No deviation in performance parameters of interest should exceed +10% anywhere along the performance curve. In addition, the first derivative of operational performance parameter should match the first derivative of simulated performance parameter in sign. Selecting the performance parameters for comparison should be dictated by available operational data, the ability of the simulator to operate in a simulated environment similar to the operational environment in which data was collected, and the scenario requirements of the simulator.

The simulator should also have systems simulated which support the operational requirements of the network environment. The way to check this on a gross level is to look at the controls and systems required to be used in the operational system and have similar systems operational in the simulator. By operational, it is implied that specific and significant cognitive or psychomotor activity is necessary using the system by the operator of the simulator. The goal is to load the psychomotor and cognitive systems of the experienced simulator operator in the same general way as in the operational system. Obviously, many shortcuts can be taken when automated entities are simulated with respect to system simulation. However, simulated task loading in automated entities should also be attempted but to a less rigorous extent than in the human operated simulator.

5.3 System similarity to operational system

The degree of similarity between the simulator and operational system is dependent upon three things: the requirements placed upon the network of simulators, the degree of similarity between the various types of simulators on the network, and the experience level of the operator of the simulator. There is another, more pragmatic issue which drives the similarity between the simulator and its operational counterpart. The issue is cost.

Cost dictates what is simulated and the degree to which a particular item is simulated. Technical and schedule issues can be translated into cost. It should be noted that all of the dependencies are subjective. There is no scientific basis on the degree of similarity between a simulator and its

operational counterpart in a network situation. For that matter, there is little empirical data to determine the degree of similarity between a simulator and its operational counterpart for any situation. [IST-TR-90-25] provides the beginnings on empirical guidance for determining the degree of similarity between a simulator and an operational system.

Requirements and utilization of the simulator network dictate the level of similarity required. For example, if a network of simulators is going to be used for evaluating the kill effectiveness of a new weapon system, then the weapon system should have a "good" weapons model and the models engaged should also be representative of the actual system. Normally, the needs of the simulator can be translated directly into the systems which must be simulated. Training is the only exception. Training simulators normally build the level of system complexity progressively. Therefore, a network of simulators used for training should provide some flexibility in order to progressively stress the trainee(s). Other types of simulator networks use the requirements process to determine which systems are simulated.

The degree of similarity between simulators on a network is also a driver in the degree of similarity between a simulator and its operational counterpart. If one wants to use networks of simulators to the best advantage, there should be an opportunity to level simulator capabilities between like simulators on a network. For example, one could question the value of evaluating new tank designs if a new high fidelity tank design is inserted into a lower fidelity environment. Some degree of technical leveling is necessary between simulators interacting on a network, or the outcomes of such interactions can be questioned.

Further, the experience level of operators on a simulator network influence the simulator's similarity with its operational counterpart. [IST-PD-90-25] notes that an individual's skills in performing a task are based on psychomotor and cognitive task loading. It is important to match these loadings between an operational system and its simulator dual if an experienced operator is using the simulator. These loadings do not have to be similar if the individual is not skilled in the working of the operational equipment. These theories help explain why SIMNET type devices (which are generally of moderate fidelity) do not have much value to experienced aviators, but why they are valuable to tank crews.

5.4 Weapons systems simulated

Weapons systems simulated in network environments should follow the same general guidance as the simulator.

5.5 Relationship to networks

A simulator's requirements change when it becomes part of a network. The simulator must now accommodate the network. The DIS standards explain many, but not all aspects of the accommodation. Significant system matters must be addressed by the designers. These questions include:

- Should non-DIS data be accepted? If so, how? If not, can parallel networks be established?
- Should simulators accept ALL DIS data or is a subset acceptable?
- If bad data is received, what should the receiving simulator do?
- If bad data is transmitted what should the sending simulator do?
- How are initialization and common simulator features (e.g., freeze, restart) to be handled?
- Do any simulators have critical data timing requirements from the network (e.g., use of MIL-STD-1553 data buses)? If so, how are these to be handled? It is important the network not be expected to supply data it cannot supply, and it is important that simulators address like data needs similarly, if possible.
- Should data filtering be consistently handled by all simulators? For example, if range filtering is used, should it be used by ALL simulators? and
- How should network bandwidth be partitioned between simulators?

The simulator network designer must also be concerned with methods to interface the simulator to the network. This includes the physical connection, the hardware used, the software used, and any overloads which may be induced by the network onto the simulator.

As noted in the networking section of this document, one can interface to the network using several different methods. The methods include the transmission media as well as the use of bridges, routers, and gateways.

The problems which should be watched from the various linkage methods include timing problems, cost, and development requirements imposed on the simulator. However, the most subtle problem can be due to exceeding the network specifications or the simulator performance parameters. For example, Ethernet limits users to 600 feet of cable and no more than two repeaters in series. A simulator indiscriminately added to a network already on the edge of its performance can cause the network to degrade or not to operate. Likewise, a simulator which can handle 400 PDUs/sec at the network interface, may need an internal mechanism to purge PDUs if its visual system is limited to three moving models. Programs have been developed to identify the potential simulator bottlenecks. The following discussion provides some insight into the use of one of those programs.

5.5.1 Data transmission capability

Simulators generate data to go onto networks. This data will be used by other simulators on the network. Two requirements are imposed on the data. First, the data must be relevant, and second, the data must be timely. Relevant data implies many details. The DIS standard is a great help in identifying relevant data for use between simulators.

Timeliness requires the data be sent frequently. Two options are available for DIS users to ensure timeliness: relative and absolute time stamping of data.

Absolute time stamping establishes a network system time which all simulators use to tag their data. Most experiments and DIS demonstrations have used a relative time stamp. Absolute timestamps may become useful when the network must operate synchronously or when timing is critical.

Relative time stamping lets the sending simulator tag the time relative to its internal clock. The receiving simulator must either assume the data is timely (i.e., effectively no time delay) or have two pieces of data which can be used to perform calculations which determine the interarrival time between data. These calculations consume computing resources and clock time. Therefore, most simulators have used relative time stamps and assumed the data arrives without delay. The result generally has been satisfactory for slow moving vehicles, such as ground vehicles. On the other hand, high speed vehicles exhibit some jerkiness in motion when time is

not considered or when network latency exceeds dead-reckoning thresholds.

The sending simulator must carefully watch the quantity and frequency of data it puts onto the network. Not being cognizant of these two quantities can lead to problems depending on the network topology. Most simulator networking experiments have used Ethernet or IEEE 802.3. Large data streams result in a greedy node effect [IST-TR-90-20, IST-CR-90-2, IST-XX-89-15] which results in other simulators not having equal access to the network. This is common with large numbers of semi-automated forces resident in one simulator host.

High frequency data transmission by a simulator using Ethernet can result in rejected transmission and increased network overhead due to a large number of collisions. These effects are manifested in nearly full Ethernet networks (transmission rates approaching 6Mbps) [IST-TR-90-20, IST-CR-90-2, IST-XX-89-15].

Other network topologies will yield other manifestations of problems inherent when data quantity and frequency near network limits. For example, although no simulator networks have been demonstrated using token ring, it is anticipated that large data quantities will result in lost data, while high frequency transmissions will be handled more efficiently than by Ethernet.

5.5.2 Data reception capability

The simulator receiving data has to carefully ensure that critical data is not lost and that it does not become overloaded. There are several bottlenecks within a simulator where data bandwidth, type, or size can have an adverse impact. These areas include the network interface system, the simulator's mathematical model of its environment, the entities and activity within the environment, and finally any external interfaces to the human operator. Interfaces to the human operator can include a visual simulation subsystem, a radar simulation subsystem, or a instructor/operator station. All of these items are common in simulators. The network interface is the first opportunity for a bottleneck to occur. The interface is also the first opportunity to filter out unwanted incoming data. The most common method of interfacing simulators to a network is through a standalone computer whose sole job is to filter data and format outgoing data for the network. It is common to buffer outgoing and incoming data until either the simulator or network is ready to process the data. Multitasking operating systems with priority and preemption aide this ability. Designers must estimate maximum

data arrival rates and data packet sizes to ensure sufficient buffering space and processing capacity is available to handle incoming data. A simulator normally has restrictions on the number of items it can process. The most significant item which limits the receiving simulator is the number of entities which can be processed by the simulator in the environment. As stated previously, if the network interface is aware of the simulator's restrictions, it can be designed to purge this data before it enters the simulator's domain.

5.5.3 Data type capability

There are other data types which must be handled appropriately by a receiving simulator. These other data types may have formats not familiar to the receiving simulator and distinguish themselves from those in the previous section. The data discussed in the previous paragraphs becomes limiting due its quantity and timeliness. This new data type could be perfectly formatted DIS data or erroneous data, but the simulator is not designed to recognize the data. This type of data passes through general purpose network interfaces without a problem but can be a problem to the receiving simulator. Resulting problems can range from minor anomalies in the simulator operation, to simulator or entire network operations halting.

The best place to take care of this data is in the network interface. If this approach is not practical, the simulator should be designed to discard unrecognized or erroneous data. If this is approach is not practical, then care should be taken to ensure that the receiving simulator does not corrupt the network or other simulators. The effective ways to ensure such problems do not occur are to properly test the simulator's performance (with good and bad data) prior to joining a simulator network. Another way is to design scenarios such that these types of problems are minimized.

The interface to the human via various simulator subsystems is another data restriction point. Computer image generation subsystems, radar simulation subsystems, and instructor/operator stations are the normally restrictive items. The limitations for each system of the receiving simulator should be analyzed for data quantity, type, and format limitations. Any limitations should be handled in a manner similar to the simulator in general.

Clearly, data reception limitations are not always easy to predict. While quantity and frequency limitations are easy to determine, they may not be known to other participants on the network. Data format problems can be discovered through rigorous testing of the simulator prior to connecting to the

network. Data quantity and frequency limitations should also be determined through testing. There are several development programs which assist in determining simulator network limitations.

One such program which analyzes network bandwidth based on data type was developed by Grumman Space and Electronics. This program was used to generate a sample traffic analysis for the CADIS standard. The program considers the bit size of each DIS PDU, adding the header size for the communication protocols (e.g., UDP/IP/IEEE 802.3), the frequency at which PDUs are generated, the mix of entity types on the network, and any other non-DIS data on the network. Table 1 depicts a sample traffic analysis. The following formula were used to determine the size of each PDU (in bits):

<u>PDU type</u>	<u>Size in bits</u>
ESPDU	1152 + 128A
FPDU	704
DPDU	800 + 128H
EPDU	192 + E(160+B(304+96T))

Where:

A = Number of articulated parts
H = Number of articulated parts hit
E = Number of emitter beams
B = Number of beams per emitter
T = Number of targets per beam

SAMPLE PDU SIZING

	A	*H*	*E*	*B*	*T*	*ESPDU*	*FPDU*	*DPDU*	*EPDU*
TANK	5	1	1	1	1	2220	1132	1356	1180
AIRCRAFT	20	2	3	1	2	4140	1132	1484	2588
SURFACE SHIP	50	5	10	1	5	7552	1132	1868	10060
						OVERHEAD BITS/PDU=			428

SAMPLE RATES PER ENTITY TYPE PER PDU TYPE

	LOW RATE				*HIGH RATE*			
	ESPDU	*FPDU*	*DPDU*	*EPDU*	*ESPDU*	*FPDU*	*DPDU*	*EPDU*
TANK	0.2	0	0	0	2	0.1	0.1	0
AIRCRAFT	0.2	0	0	0	8	0.1	0.1	0
SURFACE SHIP	0.2	0	0	0	1	0.1	0.1	0

SAMPLE EXERCISE TRAFFIC ESTIMATES

% ENTITIES AT HIGH RATE		*0%*	*20%*	*40%*	*60%*	*80%*	*100%*
% ENTITIES AT LOW RATE		*100%*	*80%*	*60%*	*40%*	*20%*	*0%*
100 TANKS		44,400	129,296	214,192	299,088	383,984	468,880
11 AIRCRAFT		9,108	80,726	152,344	223,962	295,580	367,198
1 SHIPS		1,510	2,779	4,047	5,315	6,584	7,852
0 TACTICAL VOICE LINKS		0	0	0	0	0	0
0 TACTICAL DATA LINKS		0	0	0	0	0	0
TOTAL TRAFFIC	BITS/SEC	*55,018*	*212,801*	*370,583*	*528,365*	*686,147*	*843,930*
	PDUs/SEC	*22*	*80*	*138*	*196*	*254*	*311*

Table 1. Sample Traffic Analysis for DIS Exercise

5.6 Relationship to environment

The environment consists of space, atmosphere, terrain, and water. For any simulator, its interaction relative to the environment is a function of both the fidelity the simulator is capable of handling and the complexity of the modeled environment. This relationship can be further refined by looking at several specific issues.

5.6.1 Visual systems features

Each simulator's view of the environment is shaped, in part, by the capabilities and requirements of the visual and/or sensor system which it uses. Scenes which are viewed by human participants and/or detected by vehicle sensors are fabricated by the visual system used by the simulator to represent the synthetic environment.

5.6.1.1 Display

The display device(s) provide the interface between the visual system and the human operators. For some applications, displays can be used between the visual system and detection instruments for which the visual system is providing synthetic imagery.

Depending on the application, a simulator can be configured with any of a variety of display devices. Each display device has strengths and weaknesses which should be considered during simulator design. Common display types include:

- Common CRT displays and video monitors (inexpensive),
- Calligraphic displays (for sharp point lights in night scenes),
- Video projectors (for inexpensive large display sizes),
- Full or partial domes with light valves (for large fields of view at greater expense - usually requires the visual system to have image warping capability),
- Heads-up displays (for instrumentation or navigation aids displayed over the visible scene), and
- Helmet-mounted displays (only needed for three dimensional viewing).

The field of display technology is currently advancing rapidly, fueled by both government and private sector investment. The next few years will see advancement in the flat-panel LCD displays, making small, high resolution, three-dimensional views affordable and more useful.

5.6.1.2 Polygon capacity

One important measurement criteron for a polygon-based visual system is its "polygon capacity." The most widely used visual systems are polygon-based, but other viable technologies exist (voxels, video disk, etc.) Polygon-based visual systems create their views out of a series of shaded, textured three-dimensional geometric polygons. Polygon capacity refers to the number of polygons a visual system can correctly handle in the course of "painting" a picture on its display device. It is important to note, however, that many visual systems have separate limitations in the number of pixels they can display, as well as the number of polygons which can be transformed, colored, and textured.

Several factors must be weighed together to determine the performance and suitability of a particular visual system to a particular task:

1) Number of display channels,

2) Resolution (in pixels) of each channel,

3) Frequency of update rate of the channels,

4) Quality of texturing (requires less polygon use), and

5) Load balancing between channels.

Items one, two, and three together indicate the total pixel output capacity within a particular visual system. Generally, these three must be traded-off against one another. For example, a certain visual system might be able to generate one channel of 1024x1024 pixel video image at a 30Hz update rate (30 Mpixel/sec) or four 512x512 pixel video images at 30Hz (also 30 MPixel/sec) or two 512x512 pixel images at 60Hz (still 30 MPixel/sec).

Item four refers to how many polygons are needed for each display channel to yield an acceptable image quality. If a visual system has good texturing capability, it can map complex photos onto single polygons and achieve startling realism with fewer polygons than a system which only shades but does not texture polygons.

Item five refers to a prioritization scheme where the visual system has been designed to "borrow" polygon capacity from less important display channels if it begins to run out of performance during a real-time scenario.

5.6.1.3 Data base

The design assumptions and construction of the environment database play a major role in shaping the overall quality of the perceived environment. The database is generally composed of a collection of features from several different primitive types:

1) Terrain polygons - in a variety of colors and textures,

2) Point lights - very bright point sources (landing lights),

3) Light strings - a series of lights in a single object,

4) Linear features - roads, rivers, etc. composed of a series of polygons. Generally have a fixed width (i.e. 10 meters) and follow an irregular path,

5) Areal features - non-linear culture with any boundary shape (i.e., lakes, cement parking lots, etc.),

6) Models - sets of polygons which represent particular objects (i.e., buildings, cars). Usually indicated by a "model reference" telling where the model (which could be stored separately) should be placed, and

7) Elevation grid - two-dimensional array of elevation points showing the height of the terrain at different locations. Use on a polygon-only visual system. Must be pre-processed before viewing in real-time.

For acceptable performance, it is usually necessary to optimize the database to the capacity of the visual system. The best results occur when the scenes displayed in each channel are near but never over the capacity of the visual system. The depth complexity of the database is therefore critical. Depth complexity can be best defined through the following example.

A visual system is displaying a particular view of a road lying on the terrain stretching out until it disappears into distant mountains. Two buildings sit next to the road some distance away, between a person's viewpoint and the mountains. The depth complexity of this scene is calculated by counting the number of polygons from the environment database which

cover a particular portion of the screen. To illustrate, see Figure 20. View #1, which looks through both of the buildings (where one appears in front of the other), has a depth complexity of five, because five polygons had to be considered before drawing a particular portion of the screen correctly. View #2 has a depth complexity of one, because all that can be seen is the background mountain. It can be inferred from this example that the environment database must be defined around the capability of the visual system for proper performance.

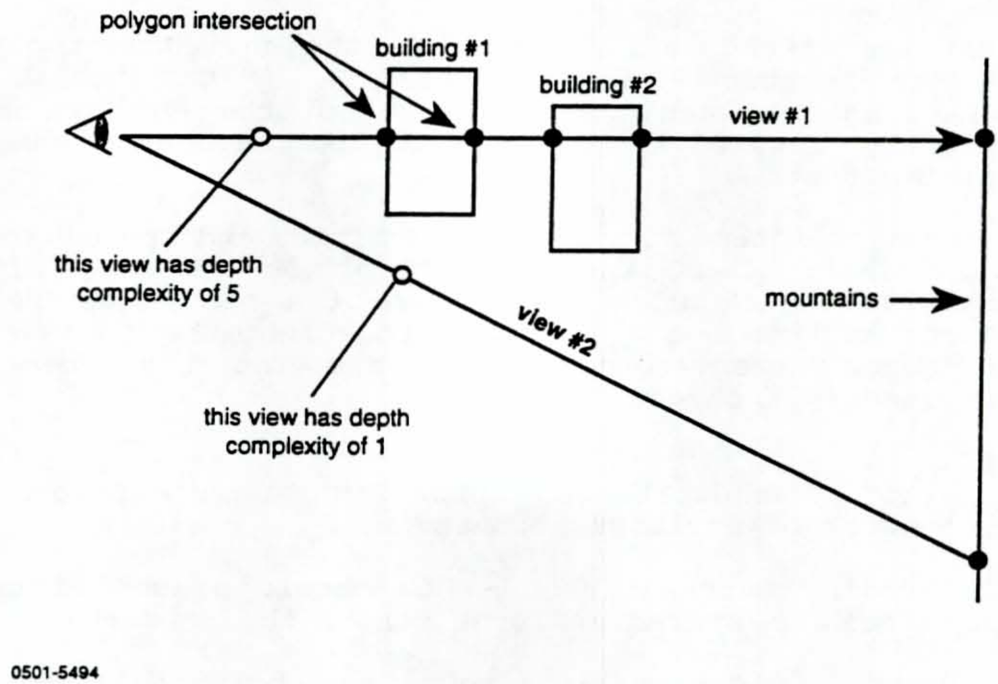


Figure 20. Viewpoint Depth Complexity

5.6.1.4 Special features

To increase the interactivity between a simulator and its environment database, several features exist or are under development for use in the visual systems. Two examples are given here.

5.6.1.4.1 Animation sequences

Many visual systems have the capability of quickly displaying a series of slightly changed features using an "animation sequence." For example, a building can explode and burn after it is hit by a munition. These sequences are often implemented by creating a series of models where the polygons of the model have different positions and colors. The visual

system cycles through the sequence of models fast enough that the operator sees smooth motion. Once built into the environment database, the animation sequences can be triggered by commands sent to the visual system from the simulation host computer. Typical scenarios can involve triggering the animation sequence after a collision is detected between objects or when a mine explodes.

5.6.1.4.2 Dynamic terrain

As earlier stated, all features in the environment database have been static - prepared offline by CAD tools. All interactions between the entities and the environment are explicitly created through animation sequences or other special effects.

The level of interaction between entities and the environment can be improved if the environment is dynamic, allowing changes to occur during the course of a real time exercise. Research programs are underway to study the issues which emerge once the environment is dynamic. The areas where study are necessary include:

1) Distributed databases - Informing other simulators on the network of environment changes,

2) Terrain representation - How should pieces of changed terrain be stored and sent across the network?

3) Network messages - Because the potential amount of information to be sent across the network is large, the messages (PDUs) must be as efficient as possible to protect network bandwidth, and

4) Simulator architecture changes - What changes will be necessary to a simulator's host computer and visual system to support the additional requirements of a dynamic environment?

When this simulator technology is in place it could enable scenarios such as combat engineers preparing battlefields before the armored vehicles arrive, craters where munitions have struck the ground, and tracks left behind ground vehicles as they move.

5.6.1.5 Sensor models

The previous examples have all been visual. However, many issues to be considered during simulator design involve

sensors (radar, night vision goggles [NVG], or infrared [IR]). Characteristics unique to sensors include their:

1) Signal-to-noise ratio,
2) Dynamic range,
3) AC Coupling,
4) Image Persistence, and
5) Automatic/manual gain controls

Currently, visual systems are just beginning to address the creation of sensor views in an accurate manner. Sensor views have historically been done by "recoloring" objects in the visual database by using an alternate color lookup table when polygons are colored. This model is inaccurate because it constrains the signature profiles of entities to be the same for all different sensors. Sensor models must be considered during the design of dynamic environments because tracks, craters, and other changed terrain must have the correct sensor profiles as well as a correct visual appearance.

Sensor models are very sensitive to conditions through which the radiated energy passes. Much as terrain relief and coloring affect visual scenes, sensor models are affected by factors such as temperature, density, and humidity. Weather and other dynamic effects of the environment also affect sensor models.

5.6.1.6 Coordinate system mapping

Standard coordinate systems (CS), along with standard algorithms to get from one CS to another, are necessary for interoperability. As an example, a particularly critical issue had to be addressed for the 1992 I/ITSEC demonstration because some participants were using the geodetic CS inside their simulators while others were using UTM or a topocentric CS.

A conflict arises because the algorithm mapping between different CSs must support consistent behavior in the two systems. Take the example of a plane being created by a simulator using a topocentric CS. The pilot is flying at an elevation of 10000 meters above the terrain (which is a flat surface defined to be tangent to the earth at some point). Another simulator, which is a ground-to-air missile simulator, uses a geodetic CS. Therefore, the pilot is using a flat-earth model derived from local contours of the ellipsoidal earth. The algorithm used to map topocentric coordinates into geodetic must make the plane look like it is 10000 meters above the same point on the earth the pilot (in the topocentric CS) thinks the plane is flying (see Figure 21).

Point P represents the plane flying over the topocentric surface and point P′ represents the plane's position over the geodetic ellipsoid. If T(x) represents the topocentric to geodetic conversion, note the following properties:

$$P' = T(P)$$
$$R = T(Q)$$
$$P' \text{ is not equal to } P$$

The two points do not represent the same position in three space, but they have consistent behavior in their respective coordinate systems because they each are 10000 meters above the same position on the earth. Therefore, the simulators can interoperate correctly.

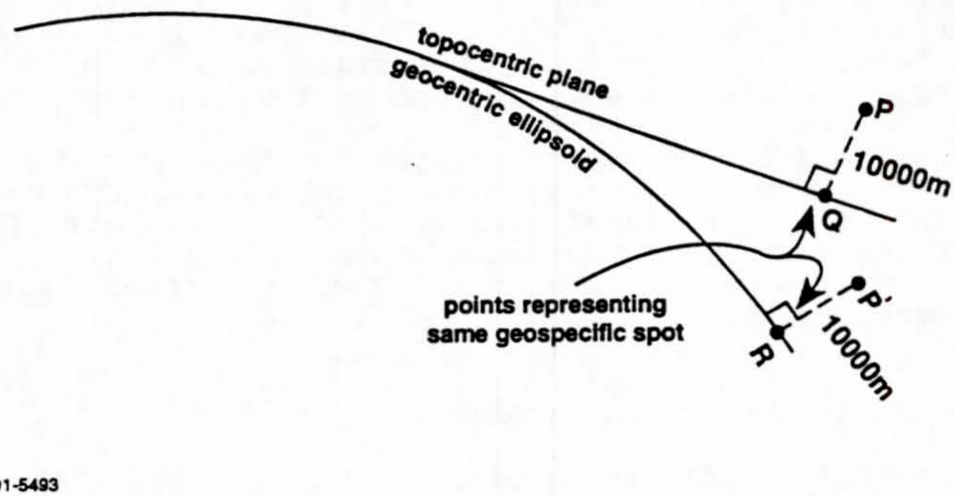


Figure 21. Mapping Vehicle Positions Between Coordinate Systems

5.6.2 Atmospheric simulation

Many types of simulators move through a simulated atmosphere in a manner analogous to their operational counterparts. As the atmosphere affects the real entities, it should also affect the behavior of these simulators. These effects are with respect to the performance of the vehicle, its systems, and its sensors.

Previous sections discussed the similarities between the dynamics models among simulators occupying a network. When the dynamics of a vehicle are represented differently in different simulators, performance differences become very apparent when the dissimilar simulators interact on a network.

The same argument can be made for the atmosphere. Each simulator, using the SIMNET and DIS paradigm, contains its own representation of the environment. Therefore, if the atmosphere is represented differently between these simulators, performance differences will arise, even if the dynamics and other simulator systems are modeled identically in the dissimilar simulators.

This approach, discussed above, is by far the most popular approach. However, the Joint Models and Simulation System (JMASS) program recognized that differences in the environment, in particular the atmosphere, could compromise the conditions they wish to create. JMASS seeks to create a simulated environment where sensor systems can be modeled and evaluated at various levels of granularity. Environmental consistency and fidelity, therefore, are extremely important to the JMASS program. JMASS creates one environment through which all data passes. This single environment is analogous to the network in the SIMNET and DIS paradigm. The JMASS environment is always consistent because it is singular.

How one handles the myriad of possible environments among simulators in a DIS network becomes problematic. The easy answer is to list the algorithms and data bases used by the different DIS simulators and analyze the impact of the environment models on the requirements levied on the network. The designer then analyzes the impact of the environmental model variation on the utilization requirements of the simulator network. If the environmental models are directly related to the utilization requirements (i.e., operational objectives) of the network, then the variation should be eliminated, or minimized, if elimination is not practical. For example, if different wing designs are to be evaluated using a simulator network, care should be taken to ensure an accurate and consistent representation of the atmosphere and weather. If human factors evaluations are the objective, consistent atmospheric models are less critical.
What does one do, though, if the environmental models are not available for evaluation? A set of tests attempting to isolate environmental model differences must be created. This is very difficult, and it is recommended that each simulator and its environment be evaluated for consistency of critical operation. If differences are detected and need to be minimized for valid results, the differences should be minimized, without regard to the cause of the difference. This approach is risky because the impact of solving one problem can cause other problems if the underlying causes of the problem are not known.

5.6.2.1 Atmospheric models

Many simulators use the atmosphere as a medium through which they move, and as a set of parameters which affect subsystem performance. Atmospheric simulation affects simulator performance, visual system performance, weapons systems performance, sensor simulation performance, and that of other simulated systems. Although the visual effects of atmospheric modeling are most apparent to the human, the modeling of the atmosphere can have a dramatic effect on the performance of the simulator. For example, atmospheric temperature, density, and humidity affect the operating performance of air breathing engines. Accurate simulations of entities which operate in the atmosphere require accurate simulation of the atmosphere. A mathematically accurate model of the dynamics of a vehicle can be seriously compromised by an inaccurate atmospheric model. The following equation demonstrates the effect of the atmosphere on vehicle performance:

$$L = .5 \rho V^2 C_L S$$

This is the equation for the lift of an aircraft. The term ρ in this equation represents the air density which varies in a predictable manner with altitude and temperature [DOMMASCH,1967]. Density appears in all six degrees of freedom forces and moments in a similar manner as it appears in lift. If density is modeled differently between simulators, the results on simulator performance will vary directly with the modeling scheme used. Therefore, it is important that static atmospheric effects be modeled consistently between simulators.

Weather modeling must be consistent between simulators in order for simulators interacting through a network to exhibit consistent behavior. Modeling weather generally affects the performance of the simulator and its subsystems in a similar manner as terrain. As the simulator moves through the simulated atmosphere, it may encounter different weather patterns. Weather will affect the ability of simulators on the network to see and be seen by other simulators in a similar manner as terrain. If the weather fronts move, the problems become more complicated but conceptually similar to dynamic terrain. Weather can also affect the dynamic performance of the simulator. Gusts, turbulence, wind, and so on can impact the ability to control and move the simulator through space.

5.6.3 Land simulation

The closer an entity is to another entity or other fixed object the more important its positional accuracy becomes. The transformations between these coordinate systems are especially important in simulating land vehicles. For example, if transforming a set of (x,y,z) coordinates in one simulator's coordinate system into another results in an anomaly of only a few meters, one may notice a tank floating above ground when viewed on the second simulator's visual display. Careful attention must be taken to ensure that algorithms used for development of terrain databases and for the run time transformation of entities' locations are consistent.

Two critical issues to consider in performing the transformations are the timing constraints of a real-time simulation network and the degree of accuracy. There is usually a trade-off between timing and accuracy [IST-TR-92-24]. There are a number of conversion algorithms in existence, but an algorithm that provides accurate results may not be fast enough to support a real-time simulation environment.

In order to support the different coordinate systems, a set of constraints should be imposed on the convergence criteria in the transformation routines. For example, if simulator A's conversion routine differs from simulator B's, imposing a 50 cm accuracy constraint will force the two simulators to interoperate to the given level of accuracy. Introducing a timing constraint, a transformation routine may reduce its computational cost with minimal use of trigonometric functions. Although the use of trigonometric functions may be unavoidable in many cases, the default values used in a particular terrain database may be computed initially at start-up time.

The orientation of a vehicle can be described using Euler angles, which consist of an ordered set of three successive rotation angles. In most simulators, a topocentric or geodetic earth-fixed axis system is used; however, DIS specifies use of a geocentric system.

In general, the body-axis coordinates are used to establish the dynamic equations of motion of the entities. Then, an earth-fixed axis coordinate system is used to describe the kinematics of the entities. This earth-fixed axis coordinate system can be considered as an inertial system in the application. All the entities in a distributed simulation environment should use the same earth-fixed axis system. If one wishes to use an earth-fixed axis system other than the

agreed upon system, then a coordinate transformation is needed [IST-TR-92-31] and the conversion algorithm should be consistent between all like entities on the network. Conversion routines should also maintain positional tolerances between all entities in a networked simulation.

The body-axis coordinate system is a Cartesian coordinate system fixed to the entity it represents and usually has its origin at the entity's center of mass. The orientations of the axes have different definitions. In SIMNET, the x-axis of the body-axis points to the vehicle's right, its y-axis points to the vehicle's front, and its z-axis points up. In DIS, the positive direction of each axis extends out the front (x-axis), the right (y-axis), and downward (z-axis). The DIS system is more common in engineering practice. Because the definitions of the body-axis systems are different, the Euler angles used to describe the orientation between SIMNET and DIS are also defined differently.

5.6.3.1 Terrain models

Simulation in the land environment is likely to involve interaction with large amounts of terrain detail within a limited range. Because entity placement on the ground affects its location and attitude, because the distance between the entities and the ground is small or nonexistent, and because the ground is usually not easily represented in sufficient detail by simple models such as planes or spheres, great accuracy and close correlation are required between the models used by different simulators.

Terrain data may be represented in a number of ways. Regularly (or irregularly) spaced elevation "post" data may be used to indicate the height of a surface. Representations of polygons in 3-space may be used. In some cases mathematical functions might be used if the contours justify it. In any case, correlation will be a concern if more than one method is used within a networked simulation to represent the same region.

Correlation problems may result from differences in the algorithms used by different simulators to process the same raw data. Polygonization of terrain post data may orient triangles differently in different simulators resulting in valleys in one case where ridges appear orthogonally in another. If polygons are used in all cases they may be treated differently, for example, by relaxing them or by interpolating them to soften their edges.

Line-of-sight determinations play an important part in simulation in many domains but in none more than in the land arena. Here, slight miscorrelations of only centimeters may

result in blockage of a clear line of sight whereas in the air environment this would be a rarity.

Terrain databases must provide more than just enough information for image generation. Surface type determines trafficability. Features such as buildings, trees, towers, rocks, and so on affect movement as well as visibility. They may be considered immovable obstacles but, if not, they must provide information on their mass, anchorage, etc.

5.6.3.2 Trafficability models

Entities in the land environment will require information from terrain databases that allows them to determine the trafficability of any area they might traverse. These models might take into account such factors as slope, surface material, effects of recent weather, and so on.

Trafficability models will be intimately related to entities' dynamics calculations. For this reason, consistency between simulators operating in the same exercise is important, otherwise one simulator might traverse a mud hole at top speed while another might bog down immediately.

5.6.3.3 Cultural models

While no man-made structures exist permanently in the sky and only a few exist in the sea, they are a fundamental part of the land environment. Roads, rails, buildings, canals, docks, power lines, pipelines, runways, bomb craters, earthworks, berms, dikes, and so on must be considered essential to a useful representation of a simulated portion of the earth's surface.

Correlation between simulators is required in this area as well. This requires common naming conventions as well as agreement on what kinds of attributes must be considered. Color, mass, hardness, flammability, and probably hundreds of other factors are potentially important.

5.6.3.4 Sensor models

Interaction with and in the land environment may require entities to sense or measure factors such as position, temperature, light level, sound, constant or varying electromagnetic fields, presence of airborne substances, etc. If the ability to sense any of these factors requires information about objects in a terrain database then agreement must be reached concerning how to represent that information.

5.6.3.5 Other models

Interaction in the land environment, as in the sea or air, requires conventions regarding many different areas. Some of these are:

A common representation of time. What time is it? How fast is it? In what increments does time pass?;

Laws of physics - Gravitational constants, refraction of light, transmission of sound or radiation through substances, dielectric constants and coefficients of friction of different materials; and

Agreement on responsibility for actions and responses, for example, detecting, reporting, and responding to reports of collisions, weapons impacts, weapons firings, message transmissions, requests for resupply, etc.

5.6.4 Ocean models

Ocean models have probably received less attention than land and air in the short history of DIS systems. Oceans probably bear a closer resemblance to atmospheres than to land because both are fluid and both tend to be more three-dimensional.

Organizations wishing to incorporate ocean environments into networked simulations will need to consider an exceedingly large number of factors if they intend to create a consistent basis for simulation between dissimilar simulators.

The following sections describe areas which must be considered by degree when modeling behavior of vehicles or other entities in the ocean environment.

5.6.4.1 Ocean physics

Of primary importance will be the physics of the medium. Some considerations in this area are:

The effects of pressure at varying depths on the structure of simulated platforms and the constraints on vehicle movement as a result of viscosity and movement of the water itself,

The dynamics of energy propagation through the medium, including shock waves, sound, light, and other regions of the electromagnetic spectrum; and

Variability and discontinuities within the medium such as those caused by differences in temperature, salinity, or amount and type of suspended matter.

5.6.4.2 Ocean movement models

The dynamic quality of the world's oceans, involving waves, tides, and currents must be considered. These vary at different rates (even seasonally). These characteristics cannot be considered in isolation. For example:

Currents may be caused by density gradients resulting from differential salinity or amount of suspended material;

Explosions may generate waves;

Wave action results in audible noise; and

Currents may affect local mean sea level (e.g., the Sargasso Sea).

5.6.4.3 Sensor models

Nearly every possible characteristic measured within the earth's oceans is potentially important in simulation. To permit consistency in a distributed simulation, the values measured at any location and time within the ocean environment must be controlled. This requires specification of algorithms or values for anything measurable, including, but definitely not limited to:

- local sea level (in earth centered coordinates),
- temperature,
- salinity,
- turbidity,
- density of marine life,
- ambient noise,
- conductivity,
- locations of temperature and other gradients, and
- location of manmade structures (platforms, cables, hydrophones, etc.).

The sorts of instruments and sensors that are likely to be involved in simulations involving the oceans include:

- sonar (active and passive),
- radar,
- lidar,
- electromagnetic monitoring, ECM, EW,

hydrophones,
seabed-based passive listening arrays (SOSUS),
bathythermographs,
pressure transducers,
salinity measurement,
infrared imaging (satellite based),
magnetic anomaly Detection (MAD),
nuclear (neutrino?) detection, and
others.

5.6.5 Interface models

Air, sea, and land models are each quite complex, yet none can be considered alone. Entities usually simulated in land environments rarely operate totally within that domain (i.e., underground) but actually operate within the lowest parts of the atmosphere. Aircraft interact significantly with the land or sea environments (and not just when launching, landing, or crashing). Although waves are noticeable some distance beneath the sea surface, they have their greatest manifestation where they interact with the atmosphere and/or the land.

Methods for describing the shape or boundaries of the oceans must be considered. The surface, at first glance, might seem to be as simple as the definition of "sea-level," a surface of constant distance from the geometric center of the WGS84 ellipsoid. However, waves modify that boundary locally at high rates, tides at lower rates, and currents, explosions, seismic activities, and moving entities unpredictably and in a highly irregular fashion.

The "bottom" of the ocean is, more properly, the surface of the solid portion of the earth and is, therefore, an extension of the land model. In the boundary region at the bottom of the sea, both land and ocean models interact. In the littoral regions, all three domains are involved.

Where oceans meet bays and ultimately rivers, the boundaries become hazy. Is the lake at the headwaters of a river part of the ocean environment or a feature within the land domain? Matters such as these must be consistently addressed in networked simulators.

As in many aspects of life, boundary conditions are where the most interesting and most demanding tests occur. Simulations and their internal models must be designed from the beginning with these boundary conditions (or tests?) in mind. It is usually very hard to retrofit new principles into pre-existing and overly simplistic designs.

6 Environments

The environment is defined as the relevant conditions simulated in the gaming area within which the players operate. Simulators normally carry their own representation of the environment. The internal representation of the environment for a simulator is tuned to that simulator's needs. The internal representation of the same environment need not be the same between players due to the way the environment is represented.

The design which emerged from SIMNET [BBN,1991] and was then adopted in DIS, was that each simulator on a network contains its individual representation of the environment. This type of design is acceptable in many cases but can lead to inconsistent simulator performance in many instances. The design objective should be to determine the internal representation of the environment used by each player by analyzing the parameters, data formats, and environment related algorithms used by the simulator. The internal representation should be described in either its internal format or with respect to some baseline which is obtainable by other players.

It should be noted that some simulations use a consistent representation of the environment between players. For example, the Joint Modeling and Simulation System [SOFTECH,1991] uses a global representation of the environment. Simulators communicating with other simulators do so through the environment model. Therefore, no inconsistencies arise due the environment because the environment is consistent between all simulators. As will be described below, there is a way to achieve a similar result in a network of simulators. However, the achievement of a consistent environment in a DIS environment is often attained by using the poorest environmental simulation amongst players.

6.1 Selecting the environment scope

The scope of the environment should be selected to be consistent with the requirements of the simulator network. For example, if one wishes to evaluate the performance of a new tank in an adverse environment under tactical conditions, then a high fidelity environmental model is necessary which can be handled by all simulators on the network. Therefore, the capabilities and uses of the individual simulators must be considered when defining the environment. The environment can be classified into three categories: atmosphere, land, and bodies of water. The gaming area will be selected from these categories depending on the simulator's capabilities.

In selecting the gaming area, several issues need to be considered. The environment must be able to encompass all the different simulator platforms involved in the simulator network. If only land based simulators (tank, personnel carriers, dismounted infantries) are involved, choosing a database with an ocean environment is not required. However, if ships and submarines are included in the network, the ocean obviously must be a requirement.

Regardless of the type of entities involved in a simulator network, a consistent representation of the environment is required. A statistical approach should be taken on the elevation heights of randomly selected points in the gaming area to ensure that some degree of terrain consistency is met. This is very important, especially when each player contains its individual representation of the environment. If inconsistencies are present, one may observe tanks driving into the ground or floating above ground when displayed on the other player's visual display. Using the I/ITSEC demonstration as an example, many land vehicles were seen to be floating above ground on dissimilar visual displays. This distortion was due to the inconsistencies in representing the environment. Consistency between other aspects of environment modeling can only be reliably obtained if the information is available from the network (i.e. PDUs).

6.2 Baseline methods

The portion of the environment through which the simulator operates must be modeled. The environment can be categorized into three areas: the atmosphere (to include space), the land, and the bodies of water. Interfaces between modeled environments also must be considered. The extent of consideration is dependent upon the simulator capabilities or the scenario considerations. For example, shoreline modeling is critical for landing troops or docking a ship. Additionally, atmosphere to earth interfaces are important for visibility and trafficability of ground vehicles. The atmosphere to sea interface is critical for modeling certain radar effects.

There are several methods which can be used to baseline the environment. The easiest method is to obtain a list of the environmental models used by each player, review the scenario developed for the network application, and analyze the interaction which can occur between players where the environment can be an influencing factor.

Once the interactions have been defined where the environment could be an influencing factor, an analysis should occur to determine if and how the influence should be mitigated. There

has been a perceived need that simulators operating on a network conduct their operations on a "level playing field" as stated earlier in this handbook. The environment is a significant factor in leveling the playing field; therefore, it must be baselined appropriately.

Baselining the environment requires selecting known and measurable parametric values. The following are good choices for basic environment models:

- ICAO standard atmosphere,
- Project 2851 terrain standard, and
- Ocean models (TBD)

6.3 Importance of consistency

A level of consistency in a simulation environment must be established. This ensures a successful distributed simulation exercise among the different simulators. Without such consistency, interaction between the entities will be inaccurate and lead to distorting anomalies. The following summarizes a few of the problems which may result from the use of inconsistent parameters.

A consistent use of offsets is required. Different parts of a database may be represented by offsets from a data base origin. A critical component of interoperability is a common interpretation of the terrain. Terrain and culture placement must be represented consistently among the different simulators. If the offsets are not consistent, ground vehicles created on two different host simulators will interact in different regions of the database. Ground entities in particular, must demonstrate a high degree of correlation, or land vehicles could be seen floating above ground on dissimilar visual displays.

Also, databases should be built from a common map reference system. This is best illustrated by an example. Values generated from the transformation of geodetic coordinates of points on the WGS 84 ellipsoid to the geocentric Cartesian coordinates, differ by as much as 20 Km, in comparison to the Cartesian coordinate values generated from a spherical earth of radius equal to the semimajor axis. This would certainly create many instances of missed targets by a missile trajectory.

Last, consistent methods of converting between the different coordinate systems achieves a higher degree of interoperability among the simulators. If an air vehicle is

1000 meters above ground, this height must be realized by all simulators regardless of which coordinate system is being utilized. If this height is not correctly represented, collisions between two air entities might never occur. Using the same coordinate transformation routines also reduces risks of the "snowball" effect. Any errors introduced during a transformation from one coordinate system to another would effectively be cancelled during the reverse process.

6.4 Assessing consistency

Consistency between aspects of a simulation environment is crucial, but very difficult to define. Evidence of its importance can be found with little effort, but the relative importance of the inconsistencies themselves and the other factors which can accentuate them, or hide them, may be very hard to determine.

The requirements placed on the simulation systems must be matched with the capabilities of the systems. The components of the larger systems must match capabilities; one weak link in a chain can cause the whole to fail. Boundaries between the responsibilities of different components must be consistently understood and implemented or there will be lacunae or conflicts of duplication. These areas are discussed below.

6.4.1 System consistency with requirements

Inconsistencies in the simulation environment may be masked, unintentionally or intentionally by selections made in scenario design.

Some applications of a simulation, such as training, may ignore or may be unaffected by discrepancies which would play havoc with an analytical application. For example, in a training application it might be the case that the human players would not notice that one simulator (with an inconsistent terrain database) flew its missile through a mountain top, but in a development application this fact could easily invalidate testing.

Inconsistencies in the capabilities of different simulators might not be apparent in "lightly" loaded scenarios. A simulator with an IG capable of drawing only a few moving models might work as well as one that handled twice as many, until a scenario exceeded that limit, at which time the inconsistency could prove fatal to the operator who did not see the undrawn enemy.

A further discussion of the ability of scenario selection to hide the shortcomings of a simulation may be found in Section 7.2.3.

6.4.2 Matching simulators with the system

Consistency between the networked simulation system and the fundamental operation of the simulators themselves is desirable, but not absolutely necessary.

This consistency is desirable because it will reduce the need for transformation of data at the simulator/network interface. It is not necessary; however, witness the 1992 I/ITSEC Interoperability Demonstration wherein most simulators operated on flat terrain and converted to geocentric to communicate via the network.

Simulators which operate at different levels of mathematical precision may not be able to resolve mathematical differences, however.

6.4.3 Matching simulators with each other

With time, ever increasing numbers of dissimilar simulators will be connected and expected to interoperate. The range of capabilities will continue to widen, but it should be anticipated that some areas will advance more rapidly than others and that these areas will not be the same for every simulator. As a consequence, it may be necessary to determine the lowest common denominator in every area which affects consistency and correlation if the idea of a "fair fight" or a "balanced" evaluation is to have any validity. Unfortunately, summing all lowest common denominators may result in a very marginal set of capabilities from simulators operating in a DIS environment. It must be decided how much inconsistency is permissible and how much inconsistency is excessive.

It is not necessarily true that all elements of an exercise must possess equal capabilities. Methods such as filtering of data may permit low-powered entities to operate in a large exercise, if the filtering is appropriate for the portion of the environment under consideration.

6.5 Comparison methods

Whether an aspect of the environment is visual, physical, or electromagnetic, it is critical that it be represented consistently on all participating systems. There are, however,

no approved methods for measuring consistency. Relatively low confidence levels have been gained through very subjective visual observation; that is, dissimilar graphics displays have been placed side-by-side and identical regions rendered and some preliminary experiments have been performed to measure target/background contrast ratios on different visual displays.

Methods must be developed to conduct specific, closely controlled measurements and correlations of all aspects of these environmental categories. Some of the areas relating to visual correlation which should be considered include:

> Comparison of the projected location of polygon vertices; Do different imaging systems draw the same features in the same places?
>
> Comparison of the colors, textures, shadings, etc. of objects rendered;
>
> Comparison of conditions under which display systems may reduce levels of fidelity of displayed models;
>
> Determination of differences in terrain elevation as results of different sampling rates, polygonization algorithms, terrain relaxation algorithms, and smoothing algorithms; and
>
> Comparison of the rendering, by different systems, of smoke, fog, clouds, haze, etc.

Some of the areas relating to physical correlation which should be considered include:

> Comparison of the results of calculations involving mass and acceleration rates, turning, falling, etc.;
>
> Comparison of results of calculations resulting from detection of collisions; and
>
> Damage models.

Some of the areas relating to correlation in the electromagnetic domain include:

> Comparison of propagation models for electromagnetic radiation;
>
> Comparison of models of the Earth's magnetic field; and
>
> Comparison of models for the dielectric constants of ground, vegetation, water, structures, etc. and their

effects on attenuation, absorption, reflection, and refraction of electromagnetic energy.

6.6 Interface boundaries between environments

In section 5.6.5, the necessity of considering the interfaces between the different aspects of the environment is discussed. These interfaces are the Air/Sea (surface), Sea/Land (ocean bottom), Air/Land (ground), Air/Sea/Land (shoreline), and Air/Space transitions. If the locations and characteristics of these regions are not consistently represented, unusual and unacceptable differences in behavior and interaction will appear.

7 Scenarios and System utilization

Scenarios are designed to utilize the simulator network system to support training, acquisition, test and evaluation, analysis, or for other non-defense applications. Care must be taken not to exceed the limitations of the networked simulation.

A scenario is tested for size and fit against the identified purpose of the simulation. Once a purpose is stated, the step-by-step systems approach to the design of a scenario is followed. Scenarios are designed to accentuate or hide the capabilities and limitations of the simulator. The scenario is evaluated objectively as a component of a system. While a scenario can hide some of the limitations of a simulation, it cannot be expected to solve shortcomings of a system. Planning for growth should be considered early in the scenario design process.

7.1 Assessing the requirement

Scenario development and networked system utilization proceed from a detailed assessment of the performance capabilities of the individual and the overall system. The performance capabilities of a networked system will determine its fitness to support training, acquisition, test and evaluation, analysis, or for other non-defense applications against a stated scenario.

Networked simulator systems can be used to demonstrate any variety of capabilities. Their use as a demonstration testbed for concept weapons development, to explore new visual capabilities, or to showcase the DIS standard PDUs has been well received.

Individual systems on the network may be incapable of sustained existence on a network due to the volume of PDU traffic. They may suffer a degraded performance which could affect their ability to interact with others on the network in a timely and appropriate fashion. These individual system limitations should be identified early in the scenario development process so that the scenario can be designed around such potential problems.

One measure of suitability for utilizing a networked system is to determine if it can support the full range of PDUs required for each of these application areas. The absence of the ability to create battlefield obscuration, for example, would limit the use of a simulation system to determine the increased effectiveness of a developmental weapon sight. While this may preclude a complete analytical comparison between the old sighting system and the candidate systems under development, it would not preclude the use of the networked system to measure the relative effectiveness in all areas other than "see and be seen."

A decision to utilize the networked system may be influenced by other considerations such as the time and expense of a full field test versus the speed and cost of a limited assessment within a networked simulation system. The decision to proceed with scenario development follows the determination that the networked system, PDUs available, and the application as measured against a scenario are adequate for the intended purpose.

A decision to proceed with scenario development on the basis that the scenario can be used to mask networked system deficiencies should be made with due caution. A scenario can be crafted to cover only so many gaps in system capabilities. The infamous case of the Sgt. York operational test is an example of modifying the scenario to suit the system under test, rather than demanding the system under test meet the requirements demanded by the scenario.

7.2 Developing the scenario

The effective design of a scenario follows the traditional five steps found in the systems approach to development.

Scenario analysis -

In this first step, the objectives of the scenario are defined in detail based on the capabilities and limitations of the network, the individual simulators on the network, and the environment available to the network. If the simulator network system can support the objectives, then the scenario

developmental process can proceed. If the system cannot support all of the objectives selected, scenario design cannot proceed until alternative objectives within the system's capability can be substituted. Analysis may reveal that the system cannot support the intended scenario. A decision to proceed with scenario development to achieve a partial utilization of the system's capabilities has to be made at this point.

Scenario design -

In this step, the refined objectives of the scenario are fitted to the capabilities and limitations of the networked system. In the design step, a trial scenario is drafted and evaluated, objective by objective, for design compatibility with the simulation system. If an objective cannot be supported by the scenario design, the design is modified until all of the selected objectives are included in the scenario.

Scenario development -

Subsequent to the analysis and design steps, a conceptual scenario is iteratively refined until the fully developed scenario is modified to achieve the stated objectives in support of the simulation.

Scenario application -

After successful development of a scenario, it is applied to the system and any gaps in the initial scenario objectives and simulator network system incompatibilities are iteratively modified until a fully mature scenario is defined.

Scenario evaluation -

This step in the scenario development process is a constant in a dynamic systems development process. The scenario should be constantly refined by feedback in the application process contained in each of the preceding steps until a robust scenario capable of meeting both the stated design goals and the system capabilities is met. If the scenario cannot be supported on the networked system, then this information is fed back to the analysis step listed above, modified and then stepped through design, development, application, and evaluation until the scenario fits the stated requirement.

Scenario are developed to fit the requirements of their intended use, to accentuate certain capabilities, and to hide specific shortcomings of the simulator system. These are discussed in the following sections.

7.2.1 Scenarios to meet the requirement

Scenarios must be designed to meet the requirements of their intended use.

Training -

The use of a networked simulation for training requires the ability for a timely after-action review (AAR) for the experience to be meaningful and effective to the trainee and trainer. Effective scenario design in training must provide a goal of achievable training objectives. The success or failure to achieve training objectives should be demonstrated by the simulation network and be discernable to the trainee in the conduct of the training exercise simulation or in the AAR.

The PDUs supported by the training simulator must be examined to determine if they adequately support the training task selected and generated within the scenario. In some instances, a simulator may support training better than the real system. For example, a real tank cannot be set on fire, but a simulator can create a realistic demonstration of a fire which enables the trainee to carry out the required response procedures.

Acquisition -

The use of a networked simulation in acquisition requires the simulation system to support a comparative evaluation plan designed to generate data to compare the required and desired capabilities of two or more systems being considered for procurement, using a carefully scripted scenario. The scenario must be written with great care so not to introduce a bias against any of the competitive systems under consideration. The scenario must be written against documented system specifications capable of being objectively quantified. The need for repeatability should also be assessed by the scenario designer(s).

A networked simulation could be used to support an acquisition scenario designed to capture and compare critical data relating to the procurement specifications concerning the capabilities of a system. Introducing networked simulation to the acquisition process would bring the benefits of distributed, real-time data transfer, capture, and documentation to the evaluation process. Subjective evaluation could be replaced with objective measures against quantifiable standards of performance stated in procurement documentation. The introduction of larger man-in-the-loop

assessments has obvious benefits to the acquisition process. Simulator networks ability to support acquisition will be suspect until such time as the simulator network scenario can be objectively assessed against an operational scenario.

Test and evaluation -

The use of a networked simulation in test and evaluation (T&E) requires the simulation system to support the T&E plan designed to generate data for comparative analysis and evaluation of tactics, techniques, or equipment using a carefully scripted scenario.

An example of this would be to use a networked simulation to support a T&E scenario designed to capture and compare data concerning the capabilities of a weapon system to detect, recognize, and identify a hostile entity within the capabilities of the simulation.

Measures of effectiveness (MOEs) may be written to define the requirements of the comparative evaluation. The scenario must be drafted and then evaluated against those MOEs to determine the capability of the simulator and the scenario to support the capture and analysis of the selected MOEs. The same caution noted above for acquisition applies to T&E and applies below for analysis.

Analysis -

The use of a networked simulation in analysis requires the capability of the simulation system to produce multiple replications of the same scenario with little variance in event timing in order to obtain meaningful MOEs with the required degree of confidence. For example, an analytical test to determine weapons design parameters would require the simulation system to support precise measurement capabilities.

While a scenario can be written to generate the required MOEs for analysis, the ability of the simulator system to meet the requirement to iteratively support precise timing and measurement demands must be examined.

Other (non-defense) -

Networked simulators allow groups to practice or experience cooperative behavior, group joining, leadership, and communication skills to name just a few of the non-military areas capable of using their interaction potential. The incorporation of network simulation into games and entertainment will require scenarios scripted to surprise, frighten, or entertain their users. Scenarios to support cooperative behavior call for the system to support group

decision-making and cooperative as well as consensually based behavior.

7.2.2 Scenarios to accentuate certain capabilities

Scenarios are designed to accentuate the capabilities of the simulator.

In training, this may highlight and accentuate the capabilities of the simulator to present hard-to-train tasks or functions. Tasks which require a high degree of repetitive procedures training, or are demanding of resources, may benefit from scenarios designed to train at increased or above real-time speeds. Scenarios may also be used to generate infrequent occurrences which are best taught self-paced. For example, individual safety procedures are best taught this way.

In acquisition, the scenario may be scripted to allow multiple iterations for assessment by a variety of evaluators, enhancing and broadening the acquisition process for a more objective evaluation by a greater body of interested users.

In test and evaluation, the use of multiple scenarios may capitalize on the ability to use a networked simulation to generate data for comparative analysis and evaluation of tactics, techniques, or equipment.

In analysis, the use of a networked simulation to support precise measurement capabilities of selected MOEs may provide a broader sampling of the data available in a shorter period of time through randomly varying only one scenario factor under analysis.

In other (non-defense), the scenario may be generated by a reactive opponent using an expert system capable of discerning and reacting to the learning curve of a participant using a networked simulator. The scenario scripted to surprise, frighten, or entertain the user will retain that ability.

7.2.3 Scenarios to hide specific shortcomings

Scenarios are designed to hide certain shortcomings of the simulator.

In training, this may generate a scenario which makes the most of the beneficial training capabilities, while down playing those which are not capable of being replicated on the system or suffer through any deficiency of the system. Tasks selected for training may be those which are less demanding.

The ability of a networked simulator's image generator to draw more than a limited number of icons may place an artificial limit on the scenario to support a virtual number of entities. The ability to train may not be impaired or reduced except in total numbers available within the simulation.

In acquisition, the scenario may have to be scripted to allow multiple iterations or a limited number of assessments by evaluators. The acquisition evaluation process may be extended to provide an objective evaluation by a greater body of interested users.

In test and evaluation, the use of tailored scenarios may capitalize on the ability to use a networked simulation to generate selected data within the capacity of the system for comparative analysis and evaluation of tactics, techniques, or equipment.

In analysis, the use of a networked simulation to support precise measurement capabilities of selected MOEs may focus on a sampling of the data available over a longer period of time through sampling of only one factor under analysis in the scenario.

In other (non-defense), the scenario may be written in a narrowly defined, reactive fashion, working against a participant using a networked simulator. The scenario can be scripted to mask specific shortcomings.

7.3 Rehearsing and evaluating the scenario

A rehearsal, coupled with the resultant feedback process of scenario evaluation, is an absolute requirement for a successful demonstration or application of a networked simulator system. Successful scenario play is the proof of the total system, not just the adequacy of the scenario. If the scenario is written to support the networked simulator system, then the design requirements of the system will be met and the application or purpose of the system will be achieved (training, acquisition, test and evaluation, analysis, or other [non-defense]).

7.3.1 The importance of seeing the implementation

The only way that the scenario can be evaluated is through the eyes of the viewer (the user or the audience). The scenario players must have the ability to creatively critique their performance, not only to judge their own performance but to obtain a sense of their individual contribution to the

collective contribution in a network of simulators. In some simulations the visual perception afforded by a different perspective (a wide screen versus a narrow Out-The-Window or gunsight perspective) adds a required dimension of importance to the scenario revision process.

7.3.2 The revision process

A clear statement of purpose for the scenario should be restated before the revision process begins in order to rule out extreme modifications requiring a total scenario rewrite. Standards of individual or group performance need to be stated in advance of a scenario exercise. Individual performance standards should be set by simulator type consensus with group approval; for example, two F/A-18s should establish performance standards. Group standards should, as a minimum, call for the rule of "non-intervention." The "non-intervention" rule basically prohibits any harmful actions such as non-PDU traffic being broadcast on the system to the detriment of others or taking "control" of another's entity by design or accident. Variance from those standards and rules of play should be approved only by a consensus to avoid dual standards of performance being developed and applied.

The scenario revision process starts with a general critique and progresses to a specific individual simulator critique. A sequential, step-by-step specific scenario critique may be useful when the quality of the overall effort is ready for the fine-tuning that comes with a detailed critique.

Scenario issues must be separated from other individual simulator or networked simulator systems problems. The individual systems differences in visual system fidelity must, as an example, be separated from other issues relating to the scenario. Once an issue is clearly defined as a scenario deficiency and determined it can be fixed by a modification then the scenario should be changed by group agreement.

7.3.3 Buffering to allow additional growth

Scenarios are developed to fit the requirements of their intended use. Planning for growth to allow additional PDUs, entities, or additional test or demonstration criteria should be considered early in the scenario design process. Allowing free play within undefined limits in a scenario requires a high degree of confidence in the individual simulator not to interrupt or interfere with other network simulators.

The application of an exercise PDU may allow for the development of the concurrent practice and play test of

scenarios. The capability to merge separate exercises into one scenario for a demonstration or application of a networked system should be considered in scenario design.

8 Evaluation methods

In order to determine simulator compliance with an established test plan, evaluation methods must be established. The following five activities create a framework through which testing can be conducted and evaluated:

Setting a testing methodology establishes the degree of testing that will be performed;

Defining the test scope specifies necessary elements of the testing procedures;

Conducting tests provides organizations different ways to access test equipment either locally or remotely;

Techniques for accumulating test data facilitate different analytical techniques; and

Data reduction/dissemination provides statistics on test results and indicates potential problems with specifications.

8.1 Testing methodologies

There are four testing methodologies that can be chosen when conducting tests: non-invasive, invasive, deductive, and inductive. Some of these methods are comprehensive and fully test simulator and network functionality, while others provide limited information about simulator/network compliance with standards. The methodology chosen will be dictated in part by time constraints, an organization's willingness to share information about simulator internals, and also by whether or not the simulator under test has been designed with verification, validation, and accreditation in mind [IST-TR-93-04].

8.1.1 Non-invasive testing

In non-invasive testing, any data has to be gathered from the network. This test method is not comprehensive due to the limited data available to the tester.

8.1.2 Invasive testing

Invasive testing implies that the tester has some access to the simulator's internal operation. This method allows testers to more fully evaluate internal algorithms for compliance.

8.1.3 Deductive testing

In deductive testing, specific data is gathered and analyzed and is used to confirm compliance with a directly related set of test criteria. The deductive approach is comprehensive yet also lengthy.

8.1.4 Inductive testing

Inductive testing, on the other hand, uses data which is gathered for one set of criteria to confirm the acceptability of other criteria or an expanded set of criteria. Inductive testing is not as comprehensive as deductive testing, but it is faster. That is, incomplete deductive testing reduces to inductive testing.

8.2 Test scope

Prior to the start of testing, several components should be in place. First, statistical sampling should be addressed to decide the measure of confidence in the chosen testing methodology. Second, criteria for participating in exercises, demonstrations, or experiments based on passing the test plan should also be established. These criteria should be communicated to all involved organizations. The last element is the test equipment. Thought should be given to the type of hardware and software required to conduct tests and analyze results.

8.2.1 Statistical sampling

Statistical methods are used to measure the confidence in inductive testing or the degree of uncertainty in deductive testing. Commonly used statistical methods can be found in [HOGG,1987].

8.2.2 Establishing criteria for participation

Criteria should be developed to determine if a System Under Test (SUT) can participate in an exercise, demonstration, or experiment. The criteria should be applied to both simulators and listen-only devices. The following criteria are examples IST developed for the 1992 I/ITSEC demonstration:

- Successful completion of tests in the test plan; and

- Each venue of the scenario (land, sea, air, and listeners) determined mutually beneficial criteria for participating in the demonstration. A SUT had to satisfy the criteria determined by its working group. In the event that no minimum requirements were set by a venue working group, the test plan served as the criteria for participation.

Prior to an exercise, demonstration, or experiment, there should be a participants' meeting. Such a meeting should be used to discuss the current state of testing. At these meetings, participants should decide what is and is not acceptable for the exercise, demonstration, or experiment. Issues should be decided by majority vote. This system can be used to address discrepancies between simulators or within a single simulator.

Every participating organization should have the "first right of refusal" for their system(s). The "second right of refusal" belongs to the group. A majority vote can exclude a company from the exercise, demonstration, or experiment as well as allow it to participate even if it cannot meet the minimum requirements stated in the test plan.

8.2.3 Special test equipment

Equipment required to conduct tests includes a "golden" test system which serves as a baseline for test compliance, as well as analytic tools to support the testing process.

8.2.3.1 Software

The software required to perform simulator testing should be designed to accommodate a wide variety of entity and behavior types. The approach effectively demonstrated by IST at the I/ITSEC was to use a Computer Generated Forces system. The CGF system allowed IST testers complete control over the entity's actions and behavior.

It is very important that the golden system undergo rigorous testing to resolve all discrepancies prior to testing other systems.

Test tools such as Data Loggers for data collection, Stealth Displays for visualization, and conversion programs to aid in interpreting data values are essential to quickly and accurately analyze test results.

8.2.3.2 Hardware

Most any type of hardware can be used as test equipment as long as it meets minimum simulator requirements. Thought should be given to selecting slower processing PCs because these often cannot produce and record data fast enough to keep up with faster workstation technology. It is recommended that the test hardware be portable so that testing is not restricted by location.

8.3 Conducting tests

There are three ways in which testing can be conducted: in-house, remotely, or using data logging capabilities.

The most desirable way to test a simulator is to bring it into a test facility. The facility should be impartial and formally recognized by some industry group or regulatory authority. Using a test facility reduces any complication with additional equipment required for remote connections and also allows the test conductor and test system operator to freely communicate about test issues.

The next method is to test the simulator remotely. This method requires special hardware (e.g., routers, gateways, modems, etc.) and software to establish the remote connection. Data can be transmitted over private or public WANs. Test coordination must be accomplished using a separate voice line.

The least desirable method for testing is to use a data logger to capture test information and then transmit it to the test conductor via mail, E-mail, or FTP. Limited testing can be conducted in this manner, however. The testing process will also be time consuming due to the delay in transferring logged files back and forth between test sites.

With any of the methods chosen, a central point of contact should be identified for scheduling tests. This person must be responsible for coordinating the test personnel required to establish connections between simulators (remote or not), to

conduct tests, and to communicate with the operators of the SUT.

8.4 Accumulating test data

When conducting tests, the test data should be accumulated in several ways. First, it should be data logged and stored electronically for analysis. It should also be recorded on test sheets so that test conductors can easily determine what tests have been conducted and where testing should continue when a break in time has occurred.

8.5 Data reduction/dissemination

When test data has been logged electronically, often large quantities of data will be captured. Therefore, a way to reduce the data for evaluation is required. A preferred method is to have an automatic test system which accepts binary files and analyzes test results. Unless agreed to by the test system, test results should be kept confidential and not released to the general public. Dissemination can occur by desensitizing results prior to their release.

9 Operation of simulation networks

Once a simulation network has been designed and implemented it must be carefully operated and managed in order to derive any benefits from it. Some practical considerations related to this rather mundane task are discussed below.

9.1 Scope

Simulation networks may be intended for research, training, analysis, or other purposes. The use of the system will determine whether it will be used in a transient or persistent mode. It will determine whether databases develop over time (persistent dynamic terrain) or remain constant and whether participating simulators are geographically dispersed or clustered.

9.1.1 Occasional use

Networked simulation systems have generally been used on an occasional basis. That is, they are switched on for a particular exercise, initialized for the purpose of the occasion, operated, then switched off or ignored. For such

operation the following simplifying assumptions can and have been made:

1) Destroyed entities remain destroyed only until the exercise is over; they need not sit in the terrain and simulate rusting for weeks or years. Therefore, they are reusable. This affects the treatment of entity IDs;

2) Foliage need not grow over terrain; damage and flood waters need not run off or evaporate. Therefore, modified terrain databases need not be maintained after an exercise and need not be distributed anew to each simulator. This affects strategies used to initialize simulators; and

3) The time in the virtual world is set at the beginning of the exercise. Nothing occurs in the virtual world before or after the exercise that is not part of simulator initialization.

Simulation networks which are operated on an occasional basis can probably rely on a more manpower-intensive control strategy. It is likely that personnel will be present at all network nodes during a scheduled exercise. With human operators present, coordination using voice telephone lines will probably be available in the event a simulator crashes or a communications disconnect occurs and an exercise must be restarted.

9.1.2 Sustained use

Simulations may be ongoing. A simulated world may continue to exist on whatever simulators are participating in an exercise over periods of time ranging from days, to weeks, or even months. Long term reliability of the networked system will become more important, but what constitutes a "reliable" system remains to be determined. The needs and desires of the users will determine what matters here but some experience may be required before these can be known. Some possibilities are discussed below; however, none of them currently exist in DIS. Therefore, participants in DIS must work together to devise strategies which can address long term network operations.

Newcomers will probably want to be able to join a simulation in progress just as some participants will have to leave (when they crash or when they move out of a region of interest). Therefore, time synchronization must be available at any time. This will become an "on-demand" requirement of the simulation management mechanisms. Simulators joining an exercise must be able to answer "What time is it?". If the precision required is not too great, time may be obtained through network queries

to a node tasked with maintaining an accessible clock. If very high precision is needed, then special hardware may be required.

Newcomers must be able to get "caught up" on all changes to assumptions about the virtual world, such as the current state of all dynamic terrain or environmental factors such as weather, time of year, and so on. Research in dynamic terrain may provide answers to questions about what information should be available here.

If a virtual world is to persist for long periods of time, then it is unlikely that people will be available around the clock to monitor the communications systems and simulators. Automatic monitoring and protocols for failure notification may then become very important. This part of simulation management will require more extensive development.

9.2 Configuration control

Very large and complex systems, such as simulation networks, require carefully maintained control of their configurations. Simulation networks consist of hardware, software, databases, and protocols at many layers, including levels involved with scheduling usage and access to the system.

With development of large networks (WANs) comes the requirement to control the communications hardware. MODEM compatibility must be ensured, and data transmission rates must be agreed upon. Also, telephone numbers, logon procedures, IDs and passwords must be determined, promulgated, and protected.

Additionally, protocols at the applications level must be determined, and revision and version numbers within protocols must be specified and their use enforced.

Databases (terrain, scenario, weapons effects, electromagnetic propagation, etc.) must be controlled.

Network address classes, also, must be determined and individual addresses must be assigned. The likelihood of dual usage of addresses implemented by mistake should be expected and potential solutions planned.

9.3 Error correction

In complex systems such as those discussed in this handbook, extremely large amounts of data are transferred. These systems rely upon error free communication or on systems that mitigate

the effect of transmission errors. Because the complexity of the communications task is so great, it should be separated from the simulation tasks as much as possible, as discussed earlier in Section 3.6. The simulators should be able to depend on the communications components to provide "perfect" service. Therefore, error control should be considered the responsibility of the network.

Error control refers to mechanisms which detect and correct errors that occur in the transmission of data. Detection and correction are separate functions. Just because a protocol performs one function does not mean it performs both.

Error detection is used to determine if bits have been altered by errors in transit. This is accomplished through the use of checksums in the Network and Transport Layers and through the Cyclic Redundancy Check (CRC) in the Data Link Layer. These mechanisms, used by the sender and receiver, perform a calculation on the bits of the PDU. If the receiver detects a discrepancy in the calculated result as compared to the stored result in the incoming PDU, it is assumed that an error has occurred and the PDU is discarded. Protocols such as Internet Protocol (IP), User Datagram Protocol (UDP), and Transmission Control Protocol (TCP) all have checksum mechanisms. Protocols such as IEEE 802.2 and HDLC are data link protocols and have CRCs.

In a connection-oriented or reliable protocol (e.g., TCP and HDLC), if a PDU is discarded due to detection of an error, the receiver can ask the sender to retransmit the corrupted PDU. Hence, error correction occurs. However, connection-oriented protocols do not actually manipulate the corrupted bits in an attempt to correct the error. There are protocols which perform this function. They are commonly used in radio and satellite communications. The drawback is that these protocols normally require up to double the amount of data to be sent in order to correct the errors.

10 A Case study: I/ITSEC 1992

In March 1992, the concept for a real-time demonstration of the Distributed Interactive Simulation (DIS) standard was conceived for the 14th Interservice/Industry Training Systems Education Conference (I/ITSEC) held in San Antonio, Texas on 2-5 November 1992. This effort was held with the concurrence of the sponsoring I/ITSEC organization, the US Air Force, and was sponsored by the Defense Modeling and Simulation Office (DMSO) and the US Army's Simulation Training and Instrumentation Command (STRICOM).

The DIS standard for Protocol Data Units and the current communications architecture was utilized along with the common visual data bases using Project 2851 (P2851) data. The demonstration was an integrated display of both standardization efforts. The Institute for Simulation and Training (IST) at the University of Central Florida coordinated the effort for the government and provided technical support to those organizations who demonstrated interoperability at the I/ITSEC. Planning Research Corporation (PRC), the P2851 contractor, prepared the data bases.

This joint activity involved a wide variety of organizations. Each participant generally brought expertise in one or more aspects of the demonstration. In particular, IST developed selected portions of the demonstration system and also served as a clearing house for interested parties desiring more information, wishing to participate, or needing help with specific technical aspects of the effort.

10.1 I/ITSEC demonstration scope

Though the extent of what DIS can support is broad, the scope of the demonstration was restricted by the limited preparation time. The I/ITSEC application was a joint demonstration that utilized manned and unmanned simulated vehicles plus one live vehicle (not meeting DIS requirements). In addition to the manned and unmanned simulators, a few I/ITSEC demonstration participants simply "listened" to the network and used the information as input to radar simulations or to a "window" into the battle environment. The I/ITSEC application demonstrated the capability of heterogeneous simulations to interact in a common environment. The degree of correlation and the realism of the exercise was limited by the lack of experience with the standards.

The scope of the demonstration was defined by the participating companies through a set of planning meetings held at IST. At these meetings, issues pertaining to the network, DIS standard, and terrain representation were discussed and voted on. Issues which required further research before coming to a decision were taken as action items by IST, studied, and presented to the participants at the following meeting. All action items and decisions were documented in a report called "Actions and Decisions" (see Appendix A) which was distributed to all participants within two weeks of the last planning meeting by E-mail, FAX, or mail. The planning meetings took place over a period of seven months. In concurrence with several meetings, tutorials were held on different components of the demonstration. The meeting dates were: 18 March, concurrently with the 6th DIS

workshop; 10 April; 19 May; 23 June; 24 June, concurrently with a SIF tutorial; 29 July; 20 August; 21 August, concurrently with a UDP/IP tutorial; and 23 September, concurrently with the 7th DIS workshop.

10.1.1 General

Over the 8 month period, 28 organizations directly supported and/or participated in the planning meetings and demonstrations. Participants were polled periodically about the types of simulators they would bring to Texas. The numbers and types of simulators varied from meeting to meeting. In the end, there were a total of 18 Send/Receive (S/R) devices (manned simulators and CGF), 22 Receive Only (RO) devices (network monitors, stealths, etc.), and 1 Send Only (SO) device used in the demonstration. This translated into 8 air simulators, 7 land simulators, 3 sea simulators, and 1 live vehicle. Of the 18 S/R devices, 4 were CGF systems. The organizations and types of simulators which participated in the demonstrations are shown in Table 2. In addition to simulator participation, the planning meetings and demonstration were supported by STRICOM, USAF ASD, DMSO, USAF Armstrong Labs, E&S, Star Technology, and PRC.

COMPANY NAME	TYPE OF SIMULATOR	MODE OF OPERATION
Loral/GE	M1 Tank Live M1 Taper Plan View Display	S/R S/R SO RO
Grumman	E2C	S/R
TSI	Stealth	RO
IST	CGF Network Monitor Data Logger Stealth	S/R RO RO RO
CAE Link	AH-64 Stealth Data Logger Data Logger	S/R RO RO RO
NTSC	F/A-18 Surface Ship	S/R S/R
BBN	PVD CGF Stealth	RO S/R RO
Hughes	UAV JSTARS	S/R RO
IDA	Stealth Data Logger PVD	RO RO RO

Table 2: I/ITSEC Demonstration Participants
S/R = Send/Receive; SO = Send Only; RO = Receive Only

COMPANY NAME	TYPE OF SIMULATOR	MODE OF OPERATION
Lockheed-Sanders	TSAD Scenario Monitor Patriot	RO RO S/R
McDonnell Douglas	F16/SAM Sites Network Monitor	S/R RO
IBM/ECC	After Action Review Battle Master M1	RO S/R S/R
NRaD	LHD Surface Ship Stealth	S/R RO
Motorola	Surface Ship	S/R
GD Land	M1	S/R
GD Air	F16	S/R
Rockwell	F16	S/R
Reflectone	Radar	RO
SG/Mak	Stealth	RO
Concurrent	Network Monitor	RO

Table 2 (Continued): I/ITSEC Demonstration Participants
S/R = Send/Receive; SO = Send Only; RO = Receive Only

The I/ITSEC participants spent a total of two weeks in Texas. The first week, 26-31 October, was used for testing and integrating the DIS simulators. Testing, performed by IST, included all aspects of networked simulation: communication protocols, DIS PDUs, terrain orientation, appearance, and interactivity. Testing and integration took place in the Gallery Hall of the San Antonio Convention Center.

The second week was the I/ITSEC Conference where two formal exercises were scheduled and presented. The first demonstration was presented during the opening session of the I/ITSEC Conference on Monday, 2 November 1993 in the Lila Cockrell Theater adjacent to the convention center exhibit hall. The second demonstration was given immediately before

the I/ITSEC banquet on Tuesday, 3 November 1993. This demonstration was given in the exhibit hall on a screen erected directly over the IST booth located at one end of the hall. In addition to the formal demonstrations, the DIS network was available for use during regular conference hours. This time was divided into:

1) free play, where participants could get on the network and engage in non-scripted play with other people, and

2) 30 minute blocks, where participants could "own" the network and conduct an exercise of their choosing.

IST developed the scenario for the formal demonstrations. The scenario was designed to provide a setting to demonstrate the capabilities of the participant's networked simulators without fear of intentional or inadvertent destruction by another player. To reduce the possibility of danger to any individual simulator, a table of lethality was designed and tested to ensure that individual players could not be destroyed by other "friendly" or "OPFOR" players.

The participants decided in early planning meetings to make the network public. Anyone could play on the network as long as he or she did not interfere with any other player on the network. The decision to develop a mutually beneficial network was based on the position to "demonstrate not evaluate" the DIS Interoperabilty Network.

During both weeks, a voice communication network was established to provide a capability to control and coordinate the rehearsal play using contractor furnished walkie-talkies.

10.1.2 Network design

The network design for the I/ITSEC demonstration consisted of two parts: one network for testing simulator interoperability during the seven months prior to leaving for Texas and another network for the actual DIS demonstration at the San Antonio Convention Center. Accordingly, the design of the network took place in two phases.

The first phase included the design and implementation of a network at IST which allowed participants to test their DIS simulators against a known DIS compliant system. The second phase of development was the design of a network which supported the demonstration of DIS during the formal exercises, the free play, and the 30 minute time slots during the week of I/ITSEC.

One issue which spanned both the IST network and the I/ITSEC network was the choice of communications protocols. Several options were available and the decision was based, in part, on the recommendation of the CADIS draft standard being developed by the DIS workshops.

10.1.2.1 DIS testbed

IST, under contract to STRICOM, is designing, developing, and implementing a DIS testbed which provides verification of the DIS standards process, provides a tool for DIS implementers, and functions as a standing demonstration mechanism which facilitates the promulgation and expanded use of DIS. The objectives of the testbed are to hasten the use of networking in real-time simulation and to reduce the risk associated with the introduction.

In particular, IST is interested in research involved with the performance, evaluation, and optimization of DIS PDUs and communication services in actual real-time simulation. The testbed is based on a modular design and uses commercial-off-the-shelf (COTS) components to the maximum extent possible. Initial capabilities of the testbed were demonstrated at I/ITSEC in November.

Currently, the testbed uses a thin Ethernet network connecting the SIMNET equipment (2 M1 simulators, MCC, Stealth, PVD, data logger, and BBN CGF) on loan to IST, the IST developed CGF and data logger, a TSI DIS/SIMNET protocol translator, a TSI portable Stealth, and a NetBlazer for long haul connection[5]. The DIS testbed is shown in Figure 22.

[5] Future versions of the network will include a laser or microwave link to the Defense Simulation Internet (DSI) through STRICOM.

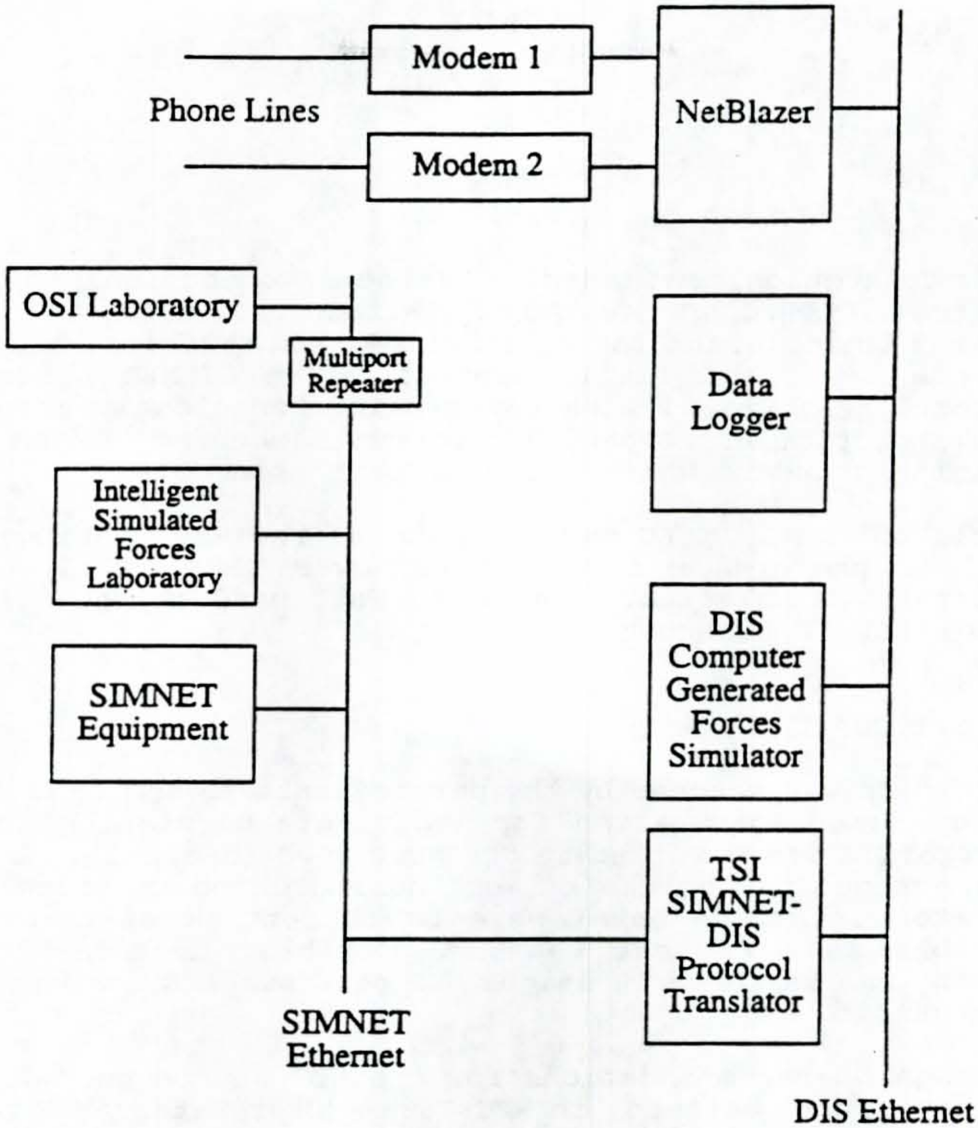


Figure 22. The DIS Testbed at IST

10.1.2.1.1 Communication protocols

The choice of protocols for the I/ITSEC demonstration was decided by popular vote. At the initial March meeting, participants made several proposals:

	Layer	Possible Choices
a)	Application	DIS

b) Network[6] UDP/IP
AP
CLTP/CLNP
Null

c) Link[7] Ethernet
IEEE 802.3

OSI's Connectionless Transport Protocol/Connectionless Network Protocol (CLTP/CLNP) was quickly eliminated as too new and too complex to implement for a near term demonstration, and a Null network layer had little support. The SIMNET Association Protocol (AP) was eliminated as being too closely associated with a particular company and product, whereas UDP/IP was an existing standard which could be purchased COTS.

A poll of the I/ITSEC participants at the May meeting showed a clear preference for Ethernet over IEEE 802.3, and so Ethernet was selected. Hence, I/ITSEC used a protocol stack of DIS/UDP/IP/Ethernet.

10.1.2.1.1.1 UDP/IP

A decision was reached by the participants to use IP broadcast during the demonstration for legitimate simulation traffic. DIS traffic was directed to UDP port 3000 (decimal). Any non-DIS messages put on the network during demonstrations (e.g., operator interface data) were to be sent point-to-point if possible and, if that was not possible, multicast. Each company was assigned 10 unique UDP port numbers for their non-DIS traffic.

IST made no recommendations for the UDP source port (the UDP source port is defined, in RFC 768 - "User Datagram Protocol" as an optional field). IST also made no recommendation as to whether the UDP optional checksum should be computed or should be sent as zero (see RFC 768). Because simulation PDUs do not require IP fragmentation, there should have been no fragmented IP traffic to UDP port 3000.

Class B IP addresses were used for the demonstration. The network number (the first two octets) was selected to be 132.170 (i.e., IST's network number). Each company was assigned unique host numbers. IST requested that hosts be numbered sequentially starting at 1 (e.g. 132.170.103.001,

[6] The Transport and Network Layers are combined as "network."

[7] The Data link and Physical layers are collectively called "link."

132.170.103.002, and so on). The IP addresses and UDP port numbers assigned to participants are shown in Table 3.

Broadcast transmission for DIS data was sent as follows: 132.170.255.255.

10.1.2.1.1.2 IST's UDP/IP implementation

Some of the I/ITSEC participants used commercial versions of UDP/IP, but IST chose to do a custom installation. The effort was engaged for several reasons:

- Because UDP/IP is a datagram protocol, its implementation is straightforward. The cost of implementation is mitigated by the gained knowledge which can be then applied to future projects. Simply buying a UDP/IP implementation would have given IST no useful insights into UDP/IP issues.

- IST, having done the UDP/IP implementation, was able to assist other participants who chose to do custom implementations. This was manifested when IST held a two hour colloquium on 21 August 1992 describing the techniques for protocol implementations in general, and UDP/IP in particular.

- The IST research simulators were among the slowest machines to appear at I/ITSEC. A custom implementation allowed them the best chance of achieving maximum throughput.

- With IST's implementation of UDP/IP, it was able to design the UDP service access points to allow simple changes among the protocols IST supports. The IST system can be built, without recompilation, to support various combinations of these protocols. This may have been impractical with a commercial product but was simple and natural using a design targeted for this system. A report detailing IST's implementation of UDP/IP/Ethernet can be found in [IST-TR-92-30].

IP ADDRESS	PARTICIPANT	UDP PORT NUMBERS
132.170.100.xxx	Loral/GE	300x[8]
132.170.101.xxx	Grumman	301x
132.170.102.xxx	TSI	302x
132.170.103.xxx	IST	303x
132.170.104.xxx	CAE-Link	304x
132.170.105.xxx	NTSC	305x
132.170.106.xxx	BBN	306x
132.170.107.xxx	Hughes	307x
132.170.108.xxx	Not Used	
132.170.109.xxx	IDA	309x
132.170.110.xxx	Lockheed	310x
132.170.111.xxx	McDonnell Douglas	311x
132.170.112.xxx	IBM/ECC	312x
132.170.113.xxx	NRaD	313x
132.170.114.xxx	Motorola	314x
132.170.115.xxx	GD Land	315x
132.170.116.xxx	GD Ft. Worth	316x
132.170.117.xxx	Rockwell	317x
132.170.118.xxx	Reflectone	318x
132.170.119.xxx	Silicon Graphics	319x
132.170.120.xxx	Concurrent Computer	320x

Table 3: IP Addresses and UDP Port Numbers

10.1.2.1.1.3 ARP

Because all simulation traffic was broadcast, no Address Resolution Protocol (ARP) requests were expected relating to the simulation itself; however, it was strongly recommended that all systems implement ARP for the purpose of testing network integrity. The purpose of ARP is to resolve the physical (i.e., Ethernet) address from a known IP address. For the demonstration, IST generated an ARP packet containing a broadcast Ethernet address and the unique IP address of each simulator. Each simulator would receive the packet (i.e., broadcast Ethernet address) and only the target simulator (i.e., unique IP address) would respond by transmitting its unique Ethernet address. This would ensure that IST could send and receive with each simulator.

[8] Loral/GE port numbers are 3001-3009.

10.1.2.2 Long haul connection

A long haul connection was established to assist the participants with dialing-in to IST to test their DIS simulators. The long haul facility not only supported the I/ITSEC demonstration pre-testing, but also provided a convenient medium for users to continue to experiment with DIS applications.

IST had two options for a long haul connection: leased lines or public switched network. Several factors determined the choice for a long haul connection:

1) simplicity of implementation,

2) ease of learning, using, and training personnel,

3) ability of remote users to configure their implementations in a short period of time in order to make a connection to the testbed, and

4) effectiveness of cost.

The first option, leased lines, utilize two identical routers at each destination connected by a leased line. If the data rate is a critical factor there is a definite advantage to this approach because it is a dedicated point-to-point connection. However, the major disadvantage is that the sender and the receiver must use the same router. Also, monthly costs for leased lines can be high. Consequently, there was no support from I/ITSEC participants to pay for leased line capability. Therefore, this option was deemed restrictive and not cost effective.

The second option, a public switched network, consists of two modems and a gateway device. The modems need not be the same brand and the transmission speed of the modems can be selected by the users. Only one gateway device is required and is rather cost effective compared to the cost of a router. The connection is established through the public phone network which charges the user by the minute rather than by a monthly fee. This option was cost effective and gives the users flexibility in choosing COTS equipment.

IST chose to implement the second option. We purchased two Telebit T3000 modems with transmission speeds of up to 57.6kbps and V32bis modem capabilities. The NetBlazer was selected as the gateway device. It functions by interfacing serial line protocols with Ethernet-type protocols. The NetBlazer's routing function makes it a flexible tool for

integrating a large number of remote users and networks into a wide area network. The NetBlazer routes packets to remote users who call in with TCP-UDP/IP communication software. The TCP-UDP/IP software must support one of the two serial line protocols, Serial Line Internet Protocol (SLIP) or Point-to-Point Protocol (PPP). Two toll free phone lines were also installed for testing purposes. Communication using the telephone lines with packetized data makes the simulator calling-in an actual node on the IST network. With this design, the DIS testbed can accommodate two remote users at one time. See Figure 23 for the hardware configuration of the long haul link. A detailed description of the IST long haul connection can be found in [IST-TR-93-01].

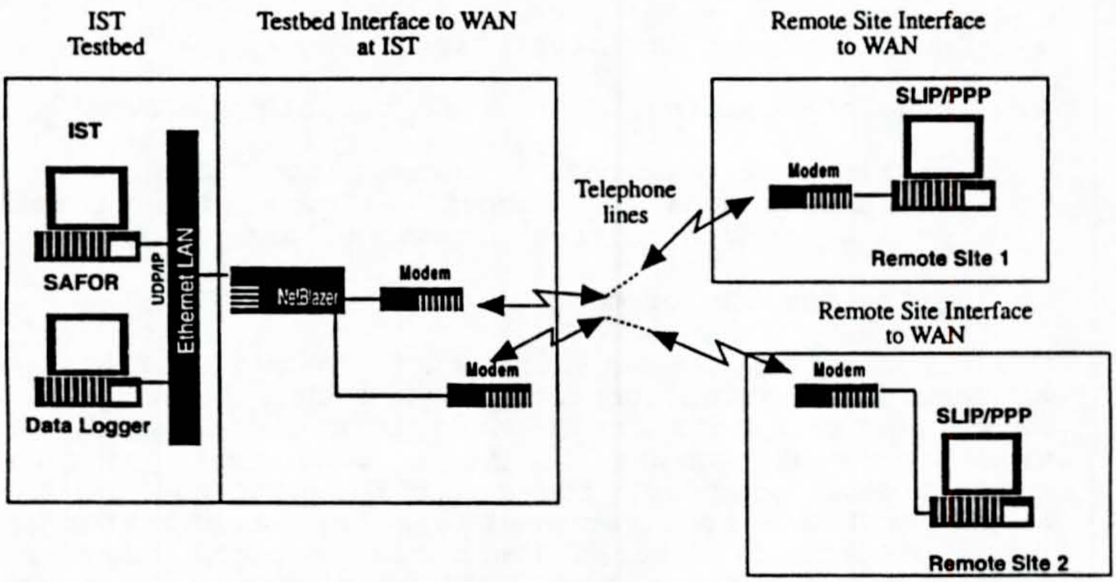


Figure 23. Hardware Configuration for the Long Haul Connection

10.1.2.3 Demonstration network

Two demonstration networks were implemented at the San Antonio Convention Center. The first network was established during the rehearsal week. This network had two configurations. At the beginning of the week it connected all participants using a star topology; at the end of the week, three subnetworks were created for land, sea, and air entities. The participants who had more than one type of simulator (i.e., land, sea, and air) were given a connection to more than one network. The second network was established when the participants moved to the southeast exhibit hall. This network was used for the formal exercises, the free play, and the 30 minute time slots. The main configuration of the network was a star topology, which consisted of eight branches

with a repeater at the main hub of the network. Figure 24 depicts the routing layout.

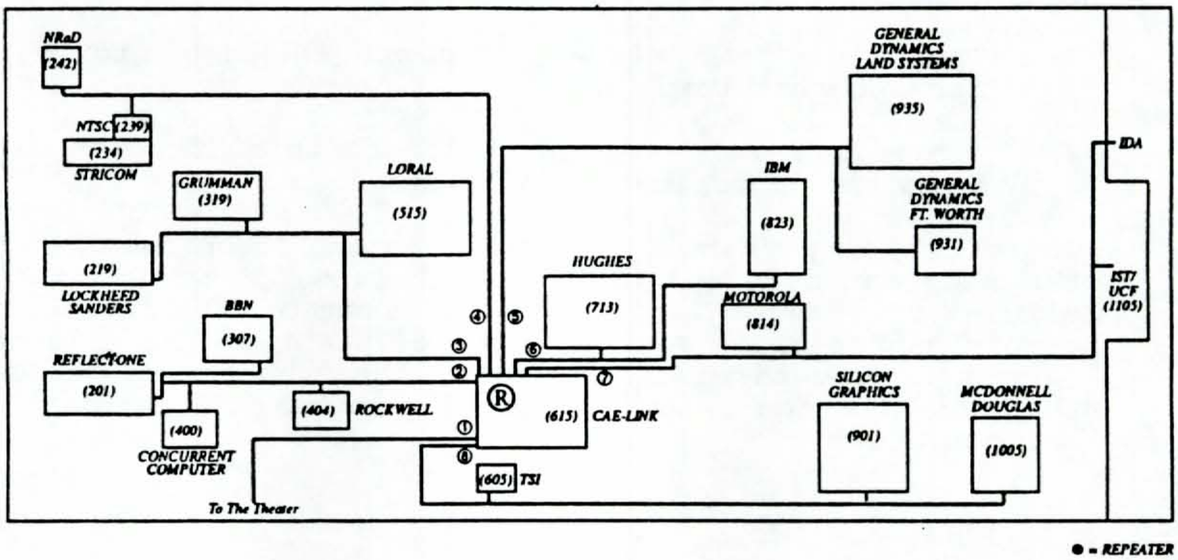


Figure 24. I/ITSEC Demonstration Network

10.1.2.3.1 Hardware configuration

The hub of the network was a multiconnect repeater located in the CAE-Link booth. This equipment was a modular, IEEE 802.3 compatible, multiport repeater that provided a flexible central platform for multisegment, multimedia Ethernet networks. This repeater allowed Ethernet segments to be connected in a bus, a star, or both bus and star configurations. The network configuration used for the I/ITSEC demonstration involved both bus and star topologies. With this configuration, signals from each segment were repeated to all other segments, so the Ethernet network could reach more users. Faulty segments could be partitioned and reconnected once the fault was eliminated. The multiconnect repeater also provided a centralized network management hub that simplified the isolation of problems.

Thin Ethernet cables were used along with barrel connectors, T-connectors, and 50 ohm terminating resistors. T-connectors were used to provide the BNC interfaces to participant's booths. Participants used these BNC connectors to access the main network. If the participants had one simulator, then the interface provided by IST connected directly to the Ethernet card of that simulator. However, most of the participants had their own local area network within their booth. In this

situation, because of the IEEE standards for thin Ethernet, a repeater, router, or bridge had to be placed between the BNC interface and the participant's network in order to prevent network failures. The IEEE 802.3 standard states the following:

1) There is a null distance between the BNC interface and the Ethernet card; and

2) There is a distance limitation of thin Ethernet cables, which is approximately 607 feet.

Therefore, by placing a repeater, router, or bridge in between the BNC connector and the Ethernet card, it was possible to eliminate the cable length problem (assuming the cable in each participant's booth was less than 607 feet). The majority of participants used repeaters inside their booths to connect to the demonstration backbone; however, several participants used bridges and routers.

10.1.2.3.2 Network tools

Several network tools were used for testing and monitoring the network. The first tool was an HP network analyzer which was used in two roles. First, it was used to check whether any traffic was on the network. Second, the analyzer was pre-programmed with the Ethernet addresses of all the participants. Using this function, it was possible to specifically evaluate the functionality of each leg of the star topology.

The multiconnect repeater also had diagnostic capabilities. The status indicator and manual segment partitioning indicators allowed diagnosis and resolution of network problems. For example, if the status indicator was not blinking, then that meant the particular segment was not functioning.

10.1.3 DIS standard

The DIS standard used in the demonstration was Version 1.0 dated 8 May 1991. Version 1.0 of the standard covers a large scope of what DIS can support. Due to the limited preparation time, certain rules and restrictions were placed on the way this version of the standard was actually used (see Section 10.1.3.2). In addition to these restrictions, a set of policies were negotiated to determine the level of interoperability to be achieved.

The DIS standard defines a set of PDUs that achieve the basic requirements for distributed interactive simulation. Each PDU is divided into two fundamental parts: a mechanism and one or more policies. Mechanisms are static and are not changed. These are the PDU fields. For each PDU field, there are a variety of policies that may be applied to it. For example, in the Entity State PDU there is a field (mechanism) for a Dead Reckoning model. There are several Dead Reckoning algorithms (policies) that can be used. The policies used in the I/ITSEC demonstration were negotiated by participants during the planning meetings held at IST.

10.1.3.1 Protocol data units

Only a subset of the PDUs listed in Appendix F of the standard were used for the demonstration. These were the Entity State, Fire, Detonation, and Collision PDUs. Though the Collision PDU was part of the exercise, air entities were exempted from collision tests. This decision was based on a quick survey taken after 20 October when IST received a request from one of the participants that air entities be exempted from collision tests. IST contacted the air participants, upon which they unanimously agreed that collisions were not necessary for the I/ITSEC DIS demonstration.

There were two clarifications made in the Entity State PDU. First, a relative timestamp was to be used in place of an absolute timestamp because of the absence of a global network timing mechanism. This required the least significant bit in the 32-bit timestamp field to be set to one. Second, in the articulation parameter record, the 64-bits articulation parameter value field was to be used to indicate the turret azimuth and gun elevation. Of the 64-bits, only the first 32-bits were used, and the remaining 32-bits were padded with zeros. Articulation parameters were only used on some of the ground based vehicles, like the M1A1, M1A2, M2, T72, and BMP1. The remainder of the allowed entity types and munitions would have no articulated parameters.

In the case of the Detonation PDU, no articulation parameters were present in the PDU because no damage models were used in the DIS demonstration. Damage assessment models were excluded to reduce the complexity of the exercise.

10.1.3.2 Policies

The goal of the formal exercise was to demonstrate DIS and to keep that exercise as simple as possible. As mentioned above, certain policies were negotiated to keep the scope of the

demonstration simple and manageable. With this in mind, the participants agreed to the following policies:

- The entity types and their 64-bit entity type record is listed below in Table 4;

- The munition types and their 64-bit entity type record is listed below in Table 5;

- In order to accommodate new entity and munition types that were not defined in Appendix H of the DIS standard, a new entity type record was assigned to each. These were the M1A2, JSTARS, and UAV for the entity types and the Penguin, RPG16, M203, 23mm HEI, 73mm, 125mm HEAT, 125mm KE, 57mm rocket, 2.75 inch a/g rocket, MK82, MK84, and 550Kg bomb for the munition types

- In order to promote consistency across participating simulation applications, IST produced a munition type versus entity type kill matrix. The "x" in the matrix means a "kill" on hit result. See Table 6;

- For dismounted infantry (DI) group representation, it was agreed that the DI would represent groups of five. This was indicated in the specific field of the entity type record. See Table 4;

- IST assigned a unique Site ID to each participating company while the assignment of Host ID was left to the company's discretion. See Table 7;

- The Exercise ID would be set to one during the demonstration;

- The bit ordering defined in Section 5 of the DIS standard was not used. The bit ordering used in the demonstration was defined with bit zero to be the least significant bit;

- To identify between the two forces, the force ID was assigned 1 (brown) to be the friendly force and 2 (green) to be the opposing force. To ensure a win-win scenario, BBN volunteered their CGF to be the opposing force, and all other entities would be friendly forces;

- Because no damage models were used in the demonstration, no articulation parameters were present in the Detonation PDU; and

- A first degree Dead Reckoning model was used. Because only the first order was used, no Dead Reckoning parameters were needed, except for the algorithm field

with value of two. It was decided that the threshold for issuance of new entity state PDUs was 3 degrees and 1m cubic.

TYPE	KIND	DOMAIN	COUNTRY	CATEGORY	SUBCAT	SPECIFIC	EXTRA	# Art. Part
M1A1	PLATFORM 1	LAND 1	USA 168	TANK 1	1	1	0	2
M1A2	PLATFORM 1	LAND 1	USA 168	TANK 1	1	2	0	2
M2	PLATFORM 1	LAND 1	USA 168	ARMORED 2	3	0	0	2
T-72	PLATFORM 1	LAND 1	USSR 164	TANK 1	2	1	0	2
BMP-1	PLATFORM 1	LAND 1	USSR 164	ARMORED 2	1	0	0	2
PATRIOT RADAR	PLATFORM 1	LAND 1	USA 168	MISC 51	0	0	0	0
PATRIOT Launcher	PLATFORM 1	LAND 1	USA 168	TOW ARTIL 5	0	0	0	0
PATRIOT STATION	PLATFORM 1	LAND 1	USA 168	L W UT VEH 7	0	0	0	0
E-2C	PLATFORM 1	AIR 2	USA 168	ELECT WAR 53	1	0	0	0
F/A-18	PLATFORM 1	AIR 2	USA 168	FIGHTER 1	14	0	0	0
F-14DF	PLATFORM 1	AIR 2	USA 168	FIGHTER 1	2	4	0	0
F-15	PLATFORM 1	AIR 2	USA 168	FIGHTER 1	7	0	0	0
F-16C	PLATFORM 1	AIR 2	USA 168	FIGHTER 1	3	3	0	0
F-16D	PLATFORM 1	AIR 2	USA 168	FIGHTER 1	3	4	0	0
A-10	PLATFORM 1	AIR 2	USA 168	ATTACK 2	4	0	0	0
FrogFoot SU-25	PLATFORM 1	AIR 2	USSR 164	ATTACK 2	8	0	0	0
APACHE AH64	PLATFORM 1	AIR 2	USA 168	ATT HELIC 6	1	0	0	0
HIND MI-24	PLATFORM 1	AIR 2	USSR 164	ATT HELIC 6	2	0	0	0
BLACK HAWK	PLATFORM 1	AIR 2	USA 168	UTIL HELIC 7	2	0	0	0
SH-60	PLATFORM 1	AIR 2	USA 168	SEA HELIC 52	3	0	0	0
JSTARS	PLATFORM 1	AIR 2	USA 168	ELECT WAR 53	6	0	0	0
E-3A	PLATFORM 1	AIR 2	USA 168	ELECT WAR 53	4	1	0	0
Umanned Air Veh	PLATFORM 1	AIR 2	USA 168	U A V 54	0	0	0	0
BEAR TU-142	PLATFORM 1	AIR 2	USSR 164	BOMBER 3	5	0	0	0
BACKFIRE TU-26	PLATFORM 1	AIR 2	USSR 164	BOMBER 3	3	0	0	0
AEGIS FFG 7	PLATFORM 1	SURFACE 3	USA 168	G.M.FRIGAT 6	1	1	0	0
H CARRIER WASP	PLATFORM 1	SURFACE 3	USA 168	AM.AS.SHIP 54	3	0	0	0
U.S.- D.I.	LIFE FORM 3	LAND 1	USA 168	DISM INFANT 1	0	5	0	0
USSR - D.I.	LIFE FORM 3	LAND 1	USSR 164	DISM INFANT 1	0	5	0	c

Table 4: Entity Types

TYPE	KIND	DOMAIN	COUNTRY	CATEGORY	SUBCAT	SPECIFIC
SPARROW AIM-7	MUNITION 2	ANTI-AIR 1	USA 168	GUIDED 1	13	0
AMRAAM AIM-120	MUNITION 2	ANTI-AIR 1	USA 168	GUIDED 1	2	0
PHOENIX	MUNITION 2	ANTI-AIR 1	USA 168	GUIDED 1	13	0
SIDE-WINDER	MUNITION 2	ANTI-AIR 1	USA 168	GUIDED 1	1	0
STINGER	MUNITION 2	ANTI-AIR 1	USA 168	GUIDED 1	15	0
MAGIC	MUNITION 2	ANTI-AIR 1	FRANCE 55	GUIDED 1	9	0
PATRIOT	MUNITION 2	ANTI-AIR 1	USA 168	GUIDED 1	16	0
SA7 GRAIL	MUNITION 2	ANTI-AIR 1	USSR 164	GUIDED 1	18	0
SA9 GASKIN	MUNITION 2	ANTI-AIR 1	USSR 164	GUIDED 1	20	0
HELLFIRE	MUNITION 2	A-ARMOR 2	USA 168	GUIDED 1	3	0
TOW	MUNITION 2	A-ARMOR 2	USA 168	GUIDED 1	1	0
MAVERICK AGM-65	MUNITION 2	A-ARMOR 2	USA 168	GUIDED 1	4	0
SPIRAL AT-6	MUNITION 2	A-ARMOR 2	USSR 164	GUIDED 1	8	0
Spandrel AT-5	MUNITION 2	A-ARMOR 2	USSR 164	GUIDED 1	7	0
HARM	MUNITION 2	A-RADAR 4	USA 168	GUIDED 1	1	0
PENGUIN	MUNITION 2	A-SHIP 6	USA 168	GUIDED 1	9	0
HARPOON	MUNITION 2	A-SHIP 6	USA 168	GUIDED 1	1	0
DRAGON	MUNITION 2	A-ARMOR 2	USA 168	GUIDED 1	2	0
RPG-16	MUNITION 2	A-ARMOR 2	USSR 164	GUIDED 1	11	0
Grenade. for M203	MUNITION 2	A-Person 1	USA 168	Ballistic 2	10	0
5.56 mm (SAW/M16)	MUNITION 2	A-Person 1	USA 168	Ballistic 2	1	0
7.62 mm	MUNITION 2	A-Person 1	USA 168	Ballistic 2	2	0
20 mm CANNON	MUNITION 2	BF Support 3	USA 168	Ballistic 2	1	0
23 mm HEI	MUNITION 2	BF Support 3	USA 168	Ballistic 2	21	0
25 mm HEI	MUNITION 2	BF Support 3	USA 168	Ballistic 2	2	0
25 mm KE	MUNITION 2	BF Support 3	USA 168	Ballistic 2	2	0

Table [illegible]: Entity Types (Continued)

TYPE	KIND	DOMAIN	COUNTRY	CATEGORY	SUBCAT	SPECIFIC
30 mm	MUNITION 2	BF Support 3	USA 168	Ballistic 2	3	0
73mm	MUNITION 2	BF Support 3	USA 168	Ballistic 2	22	0
105 mm HEAT	MUNITION 2	BF Support 3	USA 168	Ballistic 2	10	0
105 mm KE	MUNITION 2	BF Support 3	USA 168	Ballistic 2	10	0
120 mm KE	MUNITION 2	BF Support 3	USA 168	Ballistic 2	11	0
120 mm CE	MUNITION 2	BF Support 3	USA 168	Ballistic 2	11	0
125 mm HEAT	MUNITION 2	BF Support 3	USA 168	Ballistic 2	23	0
125 mm KE	MUNITION 2	BF Support 3	USA 168	Ballistic 2	23	0
57mm Rocket	MUNITION 2	BF Support 3	USA 168	Ballistic 2	24	0
2.75 inch a/g rocket	MUNITION 2	BF Support 3	USA 168	Ballistic 2	20	0
MK82 BOMB	MUNITION 2	BF Support 3	USA 168	Ballistic 2	18	0
MK84 BOMB	MUNITION 2	BF Support 3	USA 168	Ballistic 2	19	0
550 Kg BOMB	MUNITION 2	BF Support 3	USA 168	Ballistic 2	25	0

Table 5: Munition Types

Matrix of Munition Type x Entity Type (X = Kill)

munition\entity	M1 A1	M1 A2	M2 /M3	T 72	BMP 2	Pat. Rdr.	Pat. Lch.	Pat. CIC	E 2C	F/A 18	F14 D/F	F 15	F 16C	F 16D	A 10	AH 64	MI 24	UH 60	SH 60	JSTARS	E 3A	UAV	SU 25	TU 142	TU 26	FFG 7	LHD 1	US DI	OPFOR DI
SPARROW									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				
AMRAAM									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				
PHOENIX									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				
SIDEWINDER									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				
MAGIC									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				
PATRIOT									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				
SA 7 (GRAIL)									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				
SA 9 (GASKIN)									X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				
HELLFIRE	X	X	X	X	X	X	X	X																				X	X
AT 6 (SPIRAL)	X	X	X	X	X	X	X	X																				X	X
TOW	X	X	X	X	X	X	X	X																				X	X
MAVERICK	X	X	X	X	X	X	X	X																				X	X
HARM						X																							
PENGUIN																										X	X		
HARPOON																										X	X		
DRAGON			X	X	X	X	X	X																				X	X
AT 4 (SPIGOT)			X	X	X	X	X	X																				X	X
RPG-7			X	X	X	X	X	X																				X	X
GRENADE-M203						X	X	X																				X	X
5.56 mm																												X	X
7.62 mm						X	X	X																				X	X
20 mm CANNON			X		X	X	X	X																				X	X
120 mm KE	X	X	X	X	X	X	X	X																				X	X
120 mm CE	X	X	X	X	X	X	X	X																				X	X
23 mm HEI			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X
25 mm HEI			X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X
25 mm KE			X		X																							X	X
30 mm			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X
73 mm			X	X	X	X	X	X																				X	X
105 mm HEAT	X	X	X	X	X	X	X	X																				X	X
105 mm KE	X	X	X	X	X																							X	X
125 mm HEAT	X	X	X	X	X	X	X	X																				X	X
125 mm KE	X	X	X	X	X																							X	X
2.75 in. Rocket	X	X	X	X	X	X	X	X																				X	X
57 mm Rocket	X	X	X	X	X	X	X	X																				X	X
MK82 Bomb	X	X	X	X	X	X	X	X																				X	X
MK84 Bomb	X	X	X	X	X	X	X	X																				X	X
550 kg HE Bomb	X	X	X	X	X	X	X	X																				X	X

Table 6: Munition Type vs. Entity Type Kill Matrix

PARTICIPANT	SITE NUMBER	HOST NUMBERS
Loral	515	5: M1 Tank 5: Live M1 104: Taper 155: Plan View
Grumman	319	1: E2C/Stealth
TSI	605	1: Stealth
IST	1105	4: CGF 6: Network Monitor
CAE Link	615	1: AH-64 2: Listen Only
NTSC	238 239	1: F/A-18 2: Ship
BBN	307	1: Obg3 2: Rhyme 3: MCC-PVD 4: Stealth 5: Obg1
Hughes	713	1: JSTARS 2: UAV
IDA	1104	1: Stealth 2: Logger
Lockheed	219	1: Bridge 2: Mite 3: Spider 4: Mouse 5: WS1 6: Snoopy 7: WS11 8: MPSO25 9: SAFDI1 10: SAFDI2

Table 7: Site and Host IDs

PARTICIPANT	SITE NUMBER	HOST NUMBERS
McDonnell Douglas	1005	1: F16
IBM/ECC	823	1: M1 2: Battle Master 3: After Action Review
NRaD	242	1: Ship 2: Stealth
Motorola	814	1: Ship
GD Land	935	1: Test Code 2: M1A2 3: M1A2 4: Stealth
GD Ft. Worth	931	1: F-16
Rockwell	404	32: Fighter
Reflectone	201:	1: Radar
SG/Mak Technologies	901:	1: Listen Only
Concurrent	401:	1: Network Monitor

Table 7 (Continued): Site and Host IDs

10.1.3.3 Coordinate conversions

There are several coordinate systems which can be used to describe the position, orientation, and motion of the entities in a simulation exercise. An in-depth study of existing publications referenced four coordinate systems: geocentric, geodetic, topocentric, and universal transverse Mercator (UTM) coordinate systems and several measurement baselines. The following are definitions of the different coordinate systems used in today's simulators:

UTM -

Universal Transverse Mercator (UTM) is a map projection and grid system adopted by the U.S. Army in 1947 for designating rectangular coordinates on large-scale military maps of the entire world. UTM is an ellipsoidal

Transverse Mercator projection to which specific parameters, such as central meridians, have been applied.

Geocentric -

The Geocentric Coordinate System is an earth-fixed coordinate system with its origin at the centroid of the earth, the x-axis passing through the prime meridian at the equator, the y-axis passing through 90 degrees east longitude at the equator, and the z-axis passing through the North Pole.

Topocentric -

The Topocentric Coordinate System is a coordinate system whose origin is on the earth's surface and aligned at a selected point with reference to east, north, and up, as distinguished from geocentric coordinates whose origin is at the center of the earth.

Geodetic -

The Geodetic Coordinate System uses the quantities of latitude, longitude, and height (ellipsoidal) to define the position of a point on the surface of the earth with respect to a reference spheroid.

WGS 84 -

World Geodetic System 1984 (WGS 84) provides the basic reference frame and geometric figure for the earth. The WGS 84 reference ellipsoid is a geocentric ellipsoid of revolution. WGS 84 is the current standard DoD geodetic system.

WGS 72 -

World Geodetic System 1972 (WGS 72) was replaced by WGS 84. The WGS 72 has a less extensive set of satellite-derived and surface data than the WGS 84 system.

The precursor to DIS, SIMNET, used the UTM coordinate system. However, DIS exercises operate over larger geographic distances. As a result of this requirement, the geocentric coordinate system was chosen to be the earth-fixed-axis coordinate system. In order to establish the coordinate transformation between the DIS and SIMNET coordinate systems (geocentric and UTM), the geodetic coordinate was introduced. To define a geodetic coordinate system, the surface of the earth is approximated by a reference ellipsoid which is an

ellipsoid of revolution defined by two parameters: the equatorial radius a = 6,378,137 meters (the semimajor axis of the ellipse) and the flattening f = 1/298.257223563. In DIS, the shape of the earth is specified using the World Geodetic System 1984 (WGS84).

Due to the dissimilar coordinate systems used by various vendors on their simulators, IST was tasked to provide an in-depth study of the existing publications on coordinate transformations and to provide a common set of algorithms to the I/ITSEC participants. A detailed study was made of previously published coordinate conversion algorithms, and a new set of parametric equations were derived for the study. Two issues considered in the study were the accuracy of the transformations and meeting the real-time needs in a simulation exercise. In the case of a geocentric to geodetic conversion, IST developed a new algorithm to locate the point on the reference ellipsoid within 50cm or less. The algorithm proved to be the most accurate and the fastest in convergence. As a result of this study, a report [IST-TR-92-24] was published.

This report failed to discuss a conversion process between UTM and the other coordinate systems due to a misunderstanding about the nature of the coordinate system used in the SIMNET protocols. It was initially misunderstood that the SIMNET protocols use a topocentric system. This clarification necessitated a UTM to geodetic algorithm. Using the UTM to geodetic algorithm did not meet the requirement of a geocentric system as defined by the DIS standard. Another step was needed to transform the geodetic coordinates into geocentric coordinates. In short, in order to convert from SIMNET to DIS, the SIMNET coordinates which are in UTM, need to be converted into geodetic coordinates and then converted into geocentric coordinates. As can be seen, converting one coordinate system into any other can be accomplished by one, or a combination of the other algorithms.

A set of equations was also derived to transform one set of orientation angles in a particular coordinate system into another. The orientation of a vehicle can be described using Euler angles, which consist of an ordered set of three successive rotation angles. The derivations focus on DIS applications, and the two simulation protocols referenced were the SIMNET and the DIS Protocols. One difference between the two protocols is in the representation of a vehicle's body axis. In the SIMNET, a vehicle's body axis is defined using a right-handed Cartesian coordinate system in meter-sized units; the body axis is defined with its x-axis pointing to the vehicle's right, its y-axis pointing to the vehicle's front, and its z-axis pointing up. In DIS, the coordinate system representing the vehicle's body axis is also defined

with a right-handed Cartesian coordinate system. However, the positive direction of the x-axis extends out to the front, the y-axis extends to the right side, and the z-axis extends downward of the vehicle. As a result of this study, a report [IST-TR-92-31] was published.

10.1.4 Terrain representation

The delivery of the terrain data base was the responsibility of the P2851 team, a joint project designed to develop common data base formats. Vendors take the common data formats and convert the data into a form suitable to operate on their computer image generators. Data from one vendor can be put into the P2851 format and be made available to other users. There are several formats available from P2851 which include the generic transform data base (GTDB) format and the SSDB interchange format (SIF). SSDB refers to the standard simulator data base which is the format P2851 uses internally to their system. The SIF data format was selected for use by I/ITSEC participants.

The SIF data base used for I/ITSEC was selected to be a 100 x 100 km area which included portions of Fort Hunter-Liggett, CA. The southwest corner of this data base was chosen to be (north 35 deg 15 min 0 secs, west 122 deg 4 min 0 secs). Terrain, culture, and models were to be prepared for this area. The source of the SIF data was initially unstated. The source was assumed to be Defense Mapping Agency DTED and DFAD. Many vendors questioned why they could not use their own DMA sources to obtain source data. It was finally revealed by P2851 personnel that the source of the SIF data was SIMNET, not DMA. The fact that SIMNET data was being used caused some initial problems among participants. These problems were eventually worked out to the satisfaction of the participants by clarifying that SIF data needs some source and that a good source was available from SIMNET.

Vendors had some initial problems using SIF data. The first problem was the lack of map products which they could use for data base development. Companies had to wait for delivery of the SIF data before their data base tasks could begin because the specific feature and terrain representations used by SIMNET were unknown unless a map or the data base were available.

The second problem related to offsets. Different parts of the data base were represented by offsets from a data base origin. The SIF data had different offsets for terrain and culture which were not initially apparent.

The third problem was coordinate conversion methods. SIF uses geodetic coordinates for position definition. Still, DIS uses geocentric coordinates and SIMNET uses UTM coordinates. Conversion routines used to create SIF from SIMNET were not provided to all participants. When IST personnel inquired about the conversion routines, separate but similar versions were provided to IST by KOAN and BBN. The routines provided were portions of the S1000 system created for SIMNET.

Some participants did not foresee the need to have consistent methods for converting between these different coordinate systems. Project 2851 did not have such routines available for participants. IST developed standard conversion routines based on both the algorithms provided by BBN/KOAN and a literature survey and then provided them to all participants.

IST originally left SIF compliance testing to the Air Force or their contractor. However, it was quickly realized that the Air Force and their contractor were primarily concerned with getting the data base ready. Therefore, matters related to data base correlation and P2851 compliance testing were not given high priority.

There were two additional difficulties with SIF data which were not previously mentioned. The first problem dealt with the shear quantity of data which made processing by PRC difficult. Data was to be delivered for the 100 x 100 km gaming area in both gridded and polygonal formats. The second problem dealt with corrections to the data base by P2851 personnel. Discontinuities in culture and terrain were discovered by PRC and revised data bases were prepared and distributed. In addition, enhancements were made to subsequent releases of the data base. Tight schedules made freezing the data base necessary.

Most of the discussion so far has referred to problems with the P2851 data base. It must be emphasized that P2851 is a new standard, as is the DIS standard. Project 2851 data does not have a large installed base of expertise or product; therefore, IST feels confident that as P2851 matures, the problems will diminish.

10.1.4.1 SIF database

Because the Hunter-Liggett database was converted from a SIMNET database into SIF, the "golden version of the data" was the 3-dimensional polygonal representation. In SIF, terrain is represented as a uniform grid of elevation posts, like DMA DTED. In this particular case, the grid was made by sampling the SIMNET polygon elevations at a one arc second interval (approximately 30 meters between posts). In the sampling

process data could be lost. Therefore, the original 3-dimensional polygons were included in the SIF distribution, so participants could choose which data format to use.

A high resolution area of 10 kilometers N/S by 30 kilometers E/W was specified as the area containing all ground vehicle activity. Participants were advised to convert the high detail area as faithfully as possible. The error threshold requested of participants was set at 1.0 meters. The southwest corner of the high detail area was (N 35 deg 53 min 23.24 secs, W 121 deg 20 min 17.07 secs).

10.1.4.2 Models

During the first planning meeting, it was decided that existing SIMNET models would be used for each entity's polygonal representations shown on each simulator's visual system. If participants chose a vehicle not available in SIMNET, they would supply to P2851 a representation of the vehicle they chose for distribution to all other participants. IST offered to provide limited model format conversion assistance to participants bringing their own data. Because no data was received for any of the non-SIMNET vehicles requested, IST used the S1000 modeling system (developed on the SIMNET program) to create the needed models. The new models were constructed with design criteria (number of polygons, type of attributes, etc.) similar to existing SIMNET models. When completed, all models were delivered to KOAN Corporation in S1000 format. The models were converted to SIF by the same software used for the Hunter-Liggett SIMNET database. As a SIMNET database, it was in S1000 format.

10.2 I/ITSEC testing

Prior to the demonstration, each simulator had to be tested for compliance with the 8 May 1991 version of the DIS standard. The testing was conducted in two ways: remotely, prior to I/ITSEC, and on-site at the San Antonio Convention Center, the week prior to I/ITSEC.

10.2.1 Pre-demonstration remote testing

An important part of preparing for the I/ITSEC DIS Interoperability Demonstration was the establishment of a long haul connection for remote testing of participants' systems using the testbed at IST.

10.2.1.1 Objectives

This section describes the remote testing that was held before I/ITSEC demonstration. Testing was conducted using three methods: in-house, via toll free telephone lines, and via the Internet.

10.2.1.2 Testing using toll free telephones lines

A detailed description of the operations, software and hardware configurations for remote testing can be found in [IST-TR-93-01]. The hardware configuration for remote testing is also described in Section 10.1.2.2.

Although the long haul facilities such as the testbed and two toll free phone lines were operational for remote testing in mid July 1992, only three organizations successfully connected and attempted to transmit packets over the wide area network. Those organizations that were successful are listed below in the order in which they were tested:

1) CAE-LINK
2) Mak Technologies
3) BB&N

1) CAE-LINK

CAE-LINK made a physical connection successfully, but did not successfully configure SLIP or PPP, therefore no simulation data was transmitted on the connection.

2) Mak Technologies

Mak made the physical connection successfully and did attempt to transmit data. However, the logged communications did not satisfy the requirements of all protocol layers and, as a consequence, did not result in a meaningful exchange of behavior.

3) BB&N

BB&N also made the physical connection successfully but, like Mak, did not successfully exchange application level data.

In cases two and three the reasons for failure were not determined. Subsequent testing at San Antonio succeeded and no further effort was expended in analyzing the failure with the remote link.

10.2.1.3 Testing using Internet

In order to test using Internet, IST set up login accounts for remote users. These users were able to remotely log into the accounts using "telnet". These accounts were used to exchange files containing data logged using copies of IST's PC based Data Logger. The six organizations which tested with IST via data logged streams were:

1) CAE-LINK,
2) BB&N,
3) Hughes,
4) GD Land Systems,
5) Mak Technologies, and
6) Lockheed-Sanders.

Due to the limited amount of this type of testing, most systems under test could only get through the PDU level tests. IST also made logged data streams available via the ADST bulletin board. These streams were for network and PDU level tests only.

10.2.2 Pre-demonstration rehearsal/testing

Minimal testing took place prior to I/ITSEC; therefore, the majority of all systems had to be tested once IST personnel arrived in Texas. During the first week, IST tested 41 systems in 84 hours. To ensure fair and impartial testing of each participant, all tests were conducted by an IST employee. Other players who had already passed tests were used to help solve problems, but they did not make decisions as to the acceptance or rejection of other player's systems.

IST used portable testbeds (i.e., PCs on wheels) to perform testing throughout the two weeks at I/ITSEC. The testbeds were used to test systems in an isolated environment.
During testing, the IST simulator was moved to the participant's work area where it was connected to a system under test (SUT). The CGF's graphical display was used to observe the entities generated by the SUT. For testing of Dead Reckoning and vehicle dynamics calculations, a visual inspection of the icon representing an entity generated by the SUT gave a good indication whether or not its movement in the XY plane correlated with heading and XY velocity. Turret azimuth was depicted.

The IST simulator was used to generate entities which were made to interact with the SUTs' simulators or simulated entities. IST's CGF entities collided with, shot at, were shot by, observed or were observed by the SUTs'.

Each SUT's test data was logged in both text and binary form using the IST PC-based data logger. Data was also recorded on test sheets. All logged data was stored on 3.5" disks and then analyzed by a member of the IST test team using the test tools described in [IST-TR-93-04]. IST testers were able to give immediate feedback on some tests, for example, incorrect timestamps, multiple collision generation, and so on. However, turn-around on formal test results was on the order of hours (sometimes as long as eight). After a SUT had passed the full range of tests, the test results were presented to the shift leader to be signed-off. The pass list was posted outside of the IST booth.

Desensitized test data is presented in [IST-TR-93-04]. By mutual agreement, each company's test results are confidential[9].

10.3 I/ITSEC demonstration

The last component of the I/ITSEC effort was the demonstration itself. The demonstration was comprised of the interoperability network, as well as the scenario. The network established for the rehearsal testing had to be reestablished in the convention center in a matter of hours prior to the conference opening. Issues with respect to set-up and maintenance had to be resolved. The scenario was developed for the opening plenary and banquet demonstrations. The scenario was dependent on the outcome of testing, therefore, the most dynamic component of the effort.

10.3.1 Utilization of the network

The chronology of the demonstration network is listed below:

1) From 26 October until 31 October testing and integration of the network components occurred in the gallery of the San Antonio Convention Center. At 7:00 A.M. on 26 October, access to the rehearsal hall was granted to IST personnel. IST organized and assigned the locations for the participants within the rehearsal hall. The next step was to lay out and test the Ethernet network. See [IST-TR-93-02] for a detailed description of network setup, testing, and operation. Testing of simulators took place 24 hours per day during this week.

2) The rehearsal ended 31 October 1992. All equipment was subsequently moved to the southeast hall. On 1 November

[9] Review of actual test data must be approved by STRICOM.

the network for the I/ITSEC demonstration was installed and debugged.

3) The actual I/ITSEC Conference was held 2 November through 4 November. In addition to the two formal demonstrations, the DIS network was available for use during regular conference hours. This time was divided into:

    1) free play, where participants could get on the network and engage in non-scripted play with other people, and

    2) 30 minute blocks, where participants could "own" the network and conduct an exercise of their choosing.

Refer to Table 8 for the dates, time slots, and the respective organizations in those time slots.

TIME	Monday November 2	Tuesday November 3	Wednesday November 4
0700 0730	Scenario Practice		Visual Test
0800 0830	Scenario Practice		Visual Test
0900 0930	Opening Plenary Demo	Free Play Free Play	Emission Test
1000 1030	Demo Continues	NRaD CAE-LINK	Network Test
1100 1130	Free Play Free Play	IST, NRaD CAE-LINK	
1200 1230	McDonnell Douglas	Link BB&N	Hall Closes
1300 1330	GD Ft. Worth Lockheed	NTSC Free Play	
1400 1430	GD Ft. Worth Armstrong	Free Play Free Play	
1500 1530	Free Play Free Play	Loral Lockheed	
1600 1630	NRaD CAE-LINK	Free Play GD Ft. Worth	
1700 1730	IST BB&N	Demo Rehearsal	
1800 1830	Hall Closes	Demo Rehearsal	
1900 1930		Banquet Demo	
2000 2030		Hall Closes	

Table 8
I/ITSEC Demonstration Chronology in San Antonio, Texas 1992

10.3.2 Scenario

As mentioned previously, I/ITSEC participants spent a total of two weeks in Texas. The first week was for testing and integrating the DIS simulators. The second week was the I/ITSEC Conference where two formal exercises were scheduled and presented. The first demonstration was presented during the opening session of the I/ITSEC Conference on Monday, 2 November 1993 in the Lila Cockrell Theater adjacent to the convention center exhibit hall. The second demonstration was given immediately before the I/ITSEC banquet on Tuesday, 3 November 1993. This demonstration was given in the exhibit hall on a screen erected directly overhead of the IST booth located at one end of the hall.

10.3.2.1 Design

IST developed the scenario for the formal demonstrations. The scenario was designed to provide a setting to demonstrate DIS interoperability and the capabilities of the participant's networked simulators without fear of intentional or inadvertent destruction by another player. To ensure a "win-only" scenario for demonstration participants, BBN's CGF system was used to provide opposing forces. They were not allowed to fight back and died when fired upon.

The control console used was a Stealth which provides an "eyeball" view into the 3-dimensional computer generated synthetic environment. The Stealth view was shown on the three center screens. The magic carpet was used to transport the audience to any point in the environment. The job of the "Stealth" operator was to give the best view of the battle to the audience.

10.3.2.2 Chronology

The scenario used for both formal demonstrations is described below:

1) Two bogeys (SU-25s) were generated by BBN and detected by the E-2C. One target was assigned to the USS Ticonderoga and the other was assigned to the F/A-18 Combat Air Patrol.

2) The first ship seen was the USS Wasp. It was generated from the NRaD booth. The NRaD ship had the ability to display any airborne or surface threat on its radar display by capturing location data from the DIS network.

3) The second ship seen was the USS Perry and was generated from the Motorola booth. The Motorola ship also had the ability to display any airborne or surface threat on its Tactical Plot, as well as to launch missiles on these threats.

4) The third ship seen was the USS Ticonderoga, generated from the NTSC booth. The NTSC ship also had the ability to display any airborne or surface threat on its SPA-25G radar and tactical plot.

5) The first bogey came within range. The *Weapons Free* command was given to the USS Ticonderoga. The Stealth was used to show results of the firing of the missile from the ships and aircraft.

6) Two F/A-18s were directed by the E-2C to intercept and destroy the second bogey. The *Weapons Loose* command was given to the F/A-18s. The lead F/A-18 was generated from the NTSC booth.

7) The second F/A-18 was generated from the Rockwell booth in the exhibit hall, but the pilot was physically located at the Rockwell plant in Los Angeles. The locations of targets and friendlies on the DIS network were being sent from the Rockwell booth via land lines to the domed simulator in California. The pilot flew his aircraft in response to these images and the resulting aircraft locations were transmitted back to the booth and into the DIS network for others to see and interact with. The Stealth was used to show results of the firing of the missile from the lead aircraft.

8) The scenario play then jumped inland to view the land forces in the Hunter-Liggett area. To save time the Stealth was attached for a ride on CAE Link's Apache helicopter. The Apache flew at over 100 knots headed north into the engagement area at Fort Hunter-Liggett.

9) The first unit seen was a Patriot detachment generated from the Lockheed Sanders booth. The Patriot simulator had the ability to display, acquire, and engage air threats on the DIS network.

10) The Patriot radar picked up two approaching enemy attack aircraft on their display and the command was given to the Patriot battery, "You have permission to fire." The Stealth was detached from the AH-64 as the Patriots battery was overflown to watch as the missiles were launched. The enemy aircraft were CGF entities generated from the McDonnell Douglas booth. The Apache continued north and spotted two enemy tanks (also CGF entities)

generated by BBN. The Apache helicopter was given the command, "You have permission to fire." The Stealth was used to spot the action and the Hellfire missile firings.

11) The next place visited was the battle positions of Task Force Alamo responsible for the defense of a critical road junction. As the Stealth approached the Task Force, four tanks were exposed. Two tanks were seen off the side the road. An M1A1 tank was deployed forward in a fixed observation position in support of the dismounted infantry to their front. The tank was generated from the IBM booth.

12) The first M1A1 tank seen was generated from the Loral booth. Two more M1A2 tanks were seen from the Stealth on the right of the road generated from the General Dynamics Land Systems booth.

13) Placed well forward of the vehicle positions was a dismounted infantry (DI) fireteam. They were located to cover a route of advance not visible from the vehicle positions. This DI fireteam was generated by the IST CGF Testbed.

14) Just ahead of the DI fireteam was seen the first of many Opposing Force (OPFOR) vehicles generated by the BBN CGF system from their booth in the exhibit hall.

15) The IST DI fireteam was ready to engage the lead enemy vehicle with a Dragon missile. The DI fireteam was given the command, "Permission to fire." The audience watched as the DI kneeled, aimed, and fired the Dragon, destroying the lead OPFOR vehicle.

16) The Stealth operator was commanded to rejoin the tanks in their battle positions and watch as the battle unfolded. The Task force was given the command, "Permission to fire." The M1 simulators engaged the OPFOR with direct fire.

17) An unmanned aerial vehicle was sent into the battle area. The UAV was generated from the Hughes booth. The UAV was assigned to fly through enemy held territory and transmit simulated real-time TV sensor visual data back to the commander. The commander seeing an advancing enemy armored column, called for close air support.

18) An F-16 was generated from the General Dynamics, Ft. Worth booth and flown from a simulated F-16 cockpit. The F-16 was tasked to engage an enemy mobile missile vehicle (a SAM). The SAM was being generated from the McDonnell Douglas booth.

10.4 Project 2851: I/ITSEC database conversion experience

The following describes the major issues involved in the I/ITSEC database conversion. After the issues are discussed, a step-by-step log of the process of conversion from SIF to SIMNET MCC format (for the IST SAF simulator) is included. Then correlation problems are discussed.

10.4.1 Reading the SIF database

IST's internal tools for visual system databases are built on MultiGen (a commercially available CAD system) and a collection of IST-written, government-domain format conversions into and out of MultiGen's format. Therefore, the first step in this database preparation (because it had to be done quickly) was to read the SIF and convert as much of the transferable information into a MultiGen format.

The SIF to MultiGen converter was written in C by a single, very strong computer engineering graduate student. The effort took about three man-months (over six calendar months). The resulting system is about 15000 lines of code, processes many of the SIF record types, and supports MultiGen in several different ways. First, the SIF terrain and culture can be converted to DTED and DFAD for MultiGen's use. Second, the cultural features can be mapped directly into MultiGen polygon-for-polygon.

10.4.2 SIMNET database assumptions

Because IST's SAF simulator was the user of our converted database, it is important to cover the database requirements for the SAF simulator.

1) BBN PVD/MCC-format databases (version 400) are used directly by the IST SAF simulator. Byte-swapping the source is required because the SAF runs on an Intel machine.

2) PVD/MCC databases have a regular array of polygons, 125 meters on a side, three or four sides only. Polygons are grouped into grids which cover one 125 meter by 125 meter area of the ground.

3) Grids are grouped 4 by 4 into load modules (totaling 500 meters on a side).

4) Within a load module, special indexing schemes are necessary to allow for the quick retrieval of polygons for SAF line of sight determination, terrain following, and other algorithms.

5) A limit of 16k bytes per load module existed because of the SAF workstation based on an IBM compatible architecture.

10.4.3 Two-dimensional and three-dimensional culture

The SIF database was delivered in two formats:

1) Elevation grid with two-dimensional (2-D) vector culture, and

2) Three-dimensional (3-D) polygons from the SIMNET database.

Both datatypes were converted to MultiGen to decide which would be more usable. The 3-D culture was not complete (missing roads and rivers) and was also very dense (high polygon count per unit area). Also, the 2-D and 3-D culture datasets had different origins when read off the tape. This was confusing at first, especially because SIF feature data is always specified relative to the origin. Therefore, we constructed a conversion program with separate translations for 2-D and 3-D culture, respectively.

10.4.4 Coordinate system transformation

Because SIF uses the geodetic coordinate system and the IST SAF uses the UTM coordinate system, the entire database had to be transformed. The standard algorithm produced by IST for all participants was used to perform this conversion.

10.4.5 Polygon clipping

A side effect of the coordinate conversions was that the 3-D culture polygons (originally created in the UTM coordinate system before conversion to SIF) had to be clipped to UTM boundaries again. IST observed that polygon vertices were translated up to about 10 centimeters during the UTM-to-geodetic-to-SIF-to-SSDB-to-SIF-UTM translation. Once the database was clipped to load modules and polygons with more than four vertices were triangulated, the polygon density was about 40 polygons per load module (up from 16 polygons per load module in the original SIMNET version).

10.4.6 Accuracy/density tradeoff

As mentioned above, when the 3-D terrain polygons were translated and clipped, the average density was twice that of the original database. If the 3-D culture had been used for culture planting (where the culture polygons are projected onto the underlying terrain), the resulting density would have been well beyond what the IST SAF was capable of processing. Therefore, a terrain database was made by down-sampling the elevation grid to a lower density and polygonizing this lower resolution grid. Then the 2-D culture was projected on the lower resolution polygons. This resulted in a database which did not always conform to the desired error threshold of 1.0 meter in the high detail area, but it was a database with a more reasonable polygon density. Even with the above process, several load modules had to be hand edited to reduce their polygon count for the IST SAF simulator.

10.4.7 Summary of processing steps

The following steps reflect the step-by-step processing performed on the SIF database to prepare it for use by the IST computer generated forces simulator. Due to the short time available for custom software development and database processing, the process described below is not optimal. Notations are made along with several of the steps suggesting improvements.

1) Ground elevations - Converted SIF elevation grid to MultiGen DED (Digital Elevation Data) format.

2) Culture - Converted SIF cultural data into DFAD culture format for planting by MultiGen.

3) Polygonization - Created terrain polygons from the elevation posts. To limit polygon density to acceptable limits, one out of every 16 posts was chosen (making polygons 400 to 500 meters on a side). Any higher density resulted in data files too large to process in multigen and too dense for use by the IST CGF simulator.

   NOTE: The density limitation was necessary because IST's production pipeline, because it was not an optimal design, increased the polygon density during processing. Therefore, density had to be low in the beginning of production for the final database to have a reasonable density.

4) Culture planting - Used MultiGen to expand and plant culture polygons on the terrain polygon surface.

5) Feature classification - Separated terrain, lineals (roads and tree lines), and areals (canopies and lakes) into three separate MultiGen files.

6) Recombination - Recombined the three features in a single data file with a consistent naming convention. Each polygon was assigned an ID beginning with a letter specifying it's feature type:

    Txxxxxxx = terrain polygons
    Lxxxxxxx = linear feature polygon
    Axxxxxxx = areal feature polygon,

7) Models - Converted SIF model references into MultiGen Flight format model references.

8) Coordinate Conversion - Translated the terrain polygons, culture polygons, and models from the geodetic coordinate system to the universal transverse mercator (UT<) coordinate system. The algorithm distributed to all I/ITSEC participants was used.

9) Clipping - Clipped terrain and culture polygons to 500 meter load modules in the UTM coordinate system. This step increased the polygon density per unit area by approximately four times.

   NOTE: The density increase would have been much less if the elevation grid had been converted to UTM before polygonization occurred. Our production schedule did not allow for elevation post surface transformation and sampling software to be developed.

10) Triangulation - Polygons with more than four sides (resulting from the clipping operation) were triangulated because the simulator can handle only three and four sided polygons. The resulting density was approximately 50 terrain polygons (not counting culture) per load module.

11) Merge models - The models created in step #7 were merged in with the terrain. This step required a "model clipping" algorithm which used the model location to decide what in which load module it belonged.

12) Merge canopies - Adjacent canopy polygons were merged into larger polygons to reduce the polygon count for these features. IST had found experimentally that without this step, the polygon count in each load module with a

canopy was greater than what the CGF simulator could handle.

NOTE: This step would not have been necessary if the terrain skin density had been lower.

13) Hand editing - Several load modules (LMs) still had too much density. These LMs were extracted, hand edited with MultiGen and reinserted into the database.

14) Planted models - IST found that models had the correct XY, but had never been "planted" at the correct terrain elevation. All models in the database were given the elevation of the terrain polygon immediately underneath them.

10.4.8 Database correlation problems

Miscorrelation can exist between two databases on two different simulators for a variety of reasons. Two prominent reasons are different sampling resolution and translational offsets. When two databases are sampled at different resolution, then one database is composed of smaller polygons, has more spatial high-frequency content, and has more faithfully reproduced small features from the original source data. Translational offsets occur when the origin of two databases are not aligned properly; therefore, the entire databases are off by the distance found between the two database origins.

After the high-detail area database had been generated for the IST SAF simulator, it was compared to the 3-D polygon reference database. An automated tool which sampled the elevation of a database at any consistent interval was used to test the two databases IST constructed against each other.

10.5 Conclusions

Several factors are important to consider, at a systems level, when planning a system for networked simulation.

1) Minimizing the interdependence of the technologies which are going to be integrated. Modular design is one key to this. Testing of modules before integration is another.

2) Estimating (and measuring whenever possible) simulator and network capabilities and requirements during the design phase.

3) Planning for testing. Designing in capabilities for tests, diagnostic, and otherwise.

4) Planning time for prototyping.

5) Planning the tests before the design.

6) Designing for boundary conditions.

7) Plan for reliability, backups, spares, spare capacities.

8) Work from written standards and protocols.

11 Bibliography and references

ADST,1992-1 "Strawman Distributed Interactive Simulation Architecture Description Document Volume II: Supporting Rationale Book I: Time/Space Coherence and Interoperability," ADST/WDL/TR-92-003010, Contract No. N61339-91-D-0001 for PMTRADE, 31 March 1992.

ADST,1992-2 "Strawman Distributed Interactive Simulation Architecture Description Document Volume II: Supporting Rationale Book II: DIS Architecture Issues," ADST/WDL/TR-92-003010, Contract No. N61339-91-D-0001 for PMTRADE, 31 March 1992.

BBN,1991 "The SIMNET Network and Protocols," BBN Report 7627, Arthur R. Pope, June 1991, BB&N Systems and Technologies, 10 Moulton Street, Cambridge, MA 02138.

DEMING,1982 Deming, W. Edwards, "Quality, Productivity, and Competitive Positions," published by MIT Center for Advanced Engineering Study, Cambridge, MA 02138, 1982.

DOMMASCH,1967 Dommasch, Sherby, and Connolly, Airplane Aerodynamics, Pitman Publishing Corp., NY, NY, 1967.

FAA,1991 "Airplane Simulator Qualification", U.S. Department of Transportation, Federal Aviation Administration, Advisory Circular AC 120-40B, 29 July 1991.

FURNISS,1992 Furniss, P., and Ashley, K., The OSI Skinny Stack, University of London Computing Centre, August 2, 1992.

HALSALL,1992 Halsall, F., Data Communications, Computer Networks and Open Systems, Addison-Wesley, NY, NY, 1992.

HOGG,1987 Hogg, R. V. and Ledoller, J., Engineering Statistics, Macmillian Publishing Co., NY, NY, 1987.

IEEE,1993 "P1278 - Version 1.2 Standards for Information Technology, Protocols for Distributed Interactive Simulation Applications", copyright 1993 by the Institute of Electrical and Electronics Engineers, Inc. 345 East 47th Street NY, NY 10017, USA IEEE Standards Dept Copyright and Permissions, 445 Hoes Lane, PO Box 1331 Piscataway, NJ 08855-1331, USA.

IETF1989a "RFC 1123, Requirements for Internet Hosts -- Application and Support", IETF, R. Braden (editor), October 1989.

IETF1989b "RFC 1122, Requirements for Internet Hosts -- Communication Layers", IETF, R. Braden (editor), October 1989.

IST-CR-90-2 "Performance Evaluation of Local area networks for real-time simulation", Institute for Simulation and Training, University of Central Florida, publication IST-CR-90-2, 6 Feb 1990.

IST-CR-92-12 "Military Standard Version 2.0 (Draft) Protocol Data Units for Entity Information and Entity Interaction in a Distributed Interactive Simulation", Institute for Simulation and Training, University of Central Florida, publication IST-CR-92-12, 4 September 1992.

IST-CR-92-19 "Communication Architecture for Distributed Interactive Simulation, Draft Military Standard", Institute for Simulation and Training, University of Central Florida, publication IST-CR-92-19, November 1992.

IST-CR-92-20 "Communication Architecture for Distributed Interactive Simulation, Draft Rationale Document", Institute for Simulation and Training, University of Central Florida, publication IST-CR-92-20, November 1992.

IST-PD-91-1 "Military Standard (Final Draft) Protocol Data Units for Entity Information and Entity Interaction in a Distributed Interactive Simulation," Institute for Simulation and Training, University of Central Florida, publication IST-PD-91-1, 8 May 1992.

IST-PD-92-2 "Military Standard Draft, Communications Architecture for Distributed Interactive Simulation (CADIS)", Contract N61339-91-C-0091, PMTRADE, DARPA, July 1992, Institute for Simulation and Training, University of Central Florida, publication IST-PD-92-2.

IST-TR-90-15 "A Testbed for Automated Entity Generation in Distributed Interactive Simulation", Institute for Simulation and Training, University of Central Florida, publication IST-TR-90-15, 15 August 1990.

IST-TR-90-20 "Simulation Network and Protocol Alternatives", Institute for Simulation and Training, University of Central Florida, publication IST-TR-90-20, 26 and 27 April 1989.

IST-TR-90-25 "Aviation Trainer Technology Test Plan Volume 1: Engineering and Behavioral Studies", Contract N61339-89-C-0045 CDRL A006, Nov 25, 1991 Institute for Simulation and Training, University of Central Florida, publication IST-TR-90-25.

IST-TR-92-17 "Specification of Distributed Interactive Simulation in the Estelle Formal Description Technique" Institute for Simulation and Training, University of Central Florida, publication IST-TR-92-17 April 23, 1992 Contract N61339-91-C-0103.

IST-TR-92-24 "Interconversions Between Different Coordinate Systems", Institute for Simulation and Training, University of Central Florida, publication IST-TR-92-24, July 1992.

IST-TR-92-30 "Use of User Datagram Protocol/Internet Protocol (UDP/IP) in Distributed Interactive Simulation (DIS)", Institute for Simulation and Training, University of Central Florida, publication IST-TR-92-30, September 11, 1992.

IST-TR-92-31 "The Orientation Representation Between Topocentric and Geocentric Coordinate Systems", Institute for Simulation and Training, University of Central Florida, publication IST-TR-92-31, August 1992.

IST-TR-93-01 "Long Haul Network to IST", Institute for Simulation and Training, University of Central Florida, publication IST-TR-93-01, January 6, 1993.

IST-TR-93-02 "Design Study of Simulator Networks", Institute for Simulation and Training, University of Central Florida, publication IST-TR-93-02, January 6, 1993.

IST-TR-93-04 "I/ITSEC DIS Interoperability Test Procedures and Results", Institute for Simulation and Training, University of Central Florida, publication IST-TR-93-04, January 28, 1993.

IST-TR-93-04 "I/ITSEC DIS Interoperability Demonstration Test Procedures and Results", Contract N61339-91-C-0103, Institute for Simulation and Training, University of Central Florida, publication IST-TR-93-04.

IST-XX-89-15 " Simulation Networks Modeling and Monitoring Final Project Report", Institute for Simulation and Training, University of Central Florida, publication IST-XX-89-15 1 August 1988 through 31 July 1989]

JMASS,1991a "Joint Modeling & Simulation System (J-MASS)

Coordinate Systems Standards", 16 August 1991, Contract No. F33615-90 C- 1457, CDRL Sequence No. 4. Prepared for: Wright-Patterson AFB, OH 45433 by: Softech, Inc. 3100 Presidential Drive, Fairborn, OH 45324-2039.

JMASS,1992a "Software Structural Model Design Methodology for the Modeling Library Components of the Joint Modeling & Simulation System (J-MASS) Program", Version 1.1, April, 1992. Prepared by Architectural Technical Working Group (ATWG). Compiled by: Gary A. Whitted, Captain, AFECO/ET, USAF for the J-MASS Program. pgs. 1-38. Notice: Distribution limited to DOD agencies and DOD contractors only; Critical Technologies. Other requests must be referred to ASD/RWWW, WPAFB, OH 45433-6523.

JMASS,1992b "DRAFT - J-MASS-SDD-1.1 Software Design Document (SDD)", 25 March 1992. Contract No. F33615-90-C-1457, CDRL Sequence No. 14 Prepared for: Wright-Patterson AFB, OH 45433 by: Softech, Inc. 3100 Presidential Drive, Fairborn, OH 45324-2039. Notice: Distribution limited to DOD agencies and DOD contractors only; Critical Technologies. Other requests must be referred to ASD/RWWW, WPAFB, OH 45433-6523.

JMASS,1992c "DRAFT - J-MASS-SSDD-0.0 System Segment Design Document for the Joint Modeling and Simulation System (J-MASS) PROGRAM", 18 May 1992. Notice: Distribution limited to DOD agencies and DOD contractors only; Critical Technologies. Other requests must be referred to ASD/RWWW, WPAFB, OH 45433-6523.

JMASS,1992d "System/Segment Specification for the Joint Modeling and Simulation System (J-MASS) Program", J-MASS-SSS-1.1 Version 1.1 7 September 1992. Prepared by: Crossbow-S Architecture Technical Working Group. Notice: Distribution limited to DOD agencies and DOD contractors only; Critical Technologies. Other requests must be referred to ASD/RWWW, WPAFB, OH 45433-6523.

MERRIAM,1986 "Webster's Ninth New Collegiate Dictionary", Merriam-Webster Inc., Publishers Springfield, MA, USA c. 1986, Editor Frederick C. Mish.

NATC,1981 "Naval Test Pilot School Flight Test Manual, Fixed Wing Stability and Control Theory and Flight Test Techniques", Naval Air Test Center, Patuxent River, Maryland, USNTPS-FTM-No. 103,1 Jan 1975, revised 1 Nov 1981.

NATC,1987 "Naval Test Pilot School Flight Test Manual, Rotary Wing Performance", Naval Air Test Center, Patuxent River, Maryland, USNTPS-FTM-No. 106, 31 Dec 1987.

ROSE,1990 Rose, M.T., The Open Book: A Practical Perspective on

OSI, Prentice Hall, Englewood Cliffs, N.J., 1990.

SOFTECH,1991 "Joint Modeling and Simulation System (J-Mass) J-MASS-CSS-1.0 Coordinate Systems Standards", 16 Aug 1991, Contract No. F33615-90-C-1457, CDRL Sequence No. 4, prepared for Wright Laboratory WL/AAWA-1 Wright Patterson AFB, OH 45433 by: Softech, Inc. 3100 Presidential Drive Fairborn, OH 45324-2039.

STALLINGS,1987a Stallings, W., Local Networks, Macmillian Publishing Co., NY, NY, 1987.

STALLINGS,1987b Stallings, W., Handbook of Computer Communications Standards, Volume 1: The Open Systems Interconnection (OSI) Model and OSI-Related Standards, Howard W. Sams & Company, Indianapolis, IN, 1987.

STALLINGS,1987c Stallings, W., Handbook of Computer Communications Standards, Volume 3: Department of Defense (DoD) Protocol Standards, Howard W. Sams & Company, Indianapolis, IN, 1987.

STRICOM,1992 "Distributed Interactive Simulation Operational Concept Draft 2.1", Sept 1992, Institute for Simulation and Training, University of Central Florida, for STRICOM.

TANENBAUM,1988 Tanenbaum, A.S., Computer Networks, Prentice Hall, Englewood Cliffs, NJ, 1988.

12 Appendix A Actions and Decisions

CASE STUDY

ACTIONS AND DECISIONS

FROM

SIMULATOR NETWORK DEVELOPMENT

FOR A DEMONSTRATION OF

DISTRIBUTED INTERACTIVE SIMULATION AND P2851

AT THE

INTERSERVICE/INDUSTRY TRAINING SYSTEMS
& EDUCATION CONFERENCE

SAN ANTONIO, TEXAS

NOVEMBER 1-4, 1992

BACKGROUND

The Institute for Simulation and Training (IST) at the University of Central Florida was informally tasked in March, 1992 by the US Army Simulation Training and Instrumentation Command (STRICOM) and the Defense Modeling and Simulation Office (DMSO) to facilitate, design, and participate in a demonstration of Distributed Interactive Simulation (DIS) protocol data units and Project 2851 (P2851) terrain data bases. The demonstration was to take place during the Interservice/Industry Systems and Education Conference (I/ITSEC). The conference was held at the Gonzalez Convention Center in San Antonio, Texas from 1-4 November 1992.
The demonstration date of 1-4 November 1992 was firm.

However, the precise series of events necessary to meet the demonstration date was not known. Initially, IST believed that the design would be completed in July, testing would occur in August and September, correction of deficiencies would take place in September and October with set-up and demonstration at the conference in early November. These dates proved to be optimistic and too general. The organization's participation indecision, coupled with late availability of critical products, resulted in the design completion being delayed until in late September. When it became apparent that the design would not be completed until this late date, a period of set-up, test, and rehearsal in San Antonio became imperative. IST coordinated and received approval for this rehearsal period from I/ITSEC officials.

IST was asked to solicit participation from as wide a group of participants as possible. IST was not to be concerned with funding for organizations participating in the demonstration. Solicitation by IST was conducted primarily through phone calls and two notices in the Commerce Business Daily.
The notices were limited in content due to constraints and because IST was not aware of the number of potential participants, nor the true scope of the task at hand. IST called for a series of meetings to flesh out the details of the demonstration. The meetings would be held essentially monthly. The meetings would be conducted in order to arrive at a plan, design, ground rules, and so on, which met the needs of the majority of participants.

A consensus based design was necessary. The Commerce Business Daily announcement contained requirements for testing, communication, and general participation. However, IST had no mechanism in place to enforce requirements levied on participants. Also, it was recognized that it would be difficult to distinguish participants from interested parties and observers. Therefore, although all monthly meetings were

open, IST requested participants confirm their participation in writing. As time moved forward, participant comments held weight and priority over interested parties and observers. It was not known, in advance, when participants would become sufficiently interested in participating in the demonstration and making the necessary financial and personnel commitments necessary to participate, rather than only observe.

IST recognized that organizations would enter and leave the demonstration development process at various times which were not under IST's control. Therefore, a system was necessary to document open and closed design and programmatic matters. It was necessary to have a system which would record decisions made, and open actions, in order to avoid lengthy explanations for parties who may have been interested in becoming a demonstration participants. As a result, IST created a mechanism called Decisions and Actions. IST also made extensive use of electronic mail (E-mail) and fax to keep participants informed of relevant information. Decisions and Actions were updated and distributed via E-mail and fax as was all other information.

The Decisions and Actions document respectively registers matters which have been resolved and those requiring some additional work prior to resolution. All matters which cannot be immediately dispositioned are called "actions." Actions are listed in the order in which they occur, have a date noting when the matter surfaced, or when additional information was noted. The individual who is to obtain information or to analyze data to resolve the matter has his or her name noted. Also, a reference to the decision to document the result of the action occurs.

The disposition of matters which can be concluded immediately or has been resolved via an action item are called "decisions." Dates indicate when information became available for the decision. Reference to an action is made where appropriate. The decisions and actions, which follow, are listed in the order which they occur and have received only minor editing from their original version. Please note that several actions could be relevant to one decision.

REVISED: 19 October 1992

DECISIONS AND ACTIONS DOCUMENT
NOTES ON THE I/ITSEC INTEROPERABILITY DEMO MEETINGS
(Parentheses indicate date of note)

DECISIONS

DECISION 1: Voice - I/ITSEC provides walkie talkies (multi-channel preferred) (4/10/92).

DECISION 2: Video taping - DDRE taping. Vendors may require approval & may tape themselves (4/10/92).

DECISION 3: Vendors will use existing characteristics of their weapons systems (4/10/92).

DECISION 4: IDA will develop scenarios (IST will provide support) (4/10/92).

DECISION 5: I/ITSEC Interop. Demo Ground Rules (4/10/92)
- Demonstrate not evaluate - Keep scope manageable
- Accumulate data - Analyze results - Minimize new development

DECISION 6: IST will define entity numbers for models if they are not in the current version of the standard (appendix) (4/10/92).

DECISION 7: All models (SIF or ASCII) must be provided to participants by July 15 (4/10/92). IST has many of the polygon models already. A list of current IST models will be provided on 5/19/92 (5/6/92). PRC and IST have gathered all models and are coordinating their delivery.

Seventeen models should be delivered this week, and the remaining will probably be delivered next week (6/1/92). IST has determined (based on limited discussions with visual vendors) that damage will be provided (visually) for man made culture (e.g., buildings, bridges), only. Moving models will only need a working and destroyed representation (5/6/92).

A decision was reached (5/19/92) that model developers will not provide damage icon models. Killed models will be painted Black
(5/30/92). IST has also developed flash and smoke models (6/23/92).

This closes ACTION items 11, 18, and 27 (6/23/92).

DECISION 8: IST will provide an operator to demonstrate different parts of the exercise. IST will try to give everyone equal time (on projection screen). Displays will also be shown on TSI's stealth and Grumman's radar display. Other participants will display the exercise in a manner consistent with their devices on the network (4/10/92).

DECISION 9: Exhibit Hall for I/ITSEC opens at 4:00 a.m., Saturday. IST can start dropping Ethernet 12 noon on Saturday of I/ITSEC (4/10/92).

DECISION 10: Bruce McDonald and Neale Cosby are the commanders (4/10/92). Based on scheduling and workload, IST may substitute another individual for Dr. McDonald in the future (5/6/92).

DECISION 11: Rules (4/10/92) - Green is foe, brown is friendly, use force - id (6/23/92).- Dead Reckoning - 1st order - Thresholds - 1 cubic meter. - No common activation point (operator), but IDA will initialize exercise.- Destroyed models will be colored black in displayed visuals (5/19/92).

- A decision was reached to use DR thresholds: 3 degrees-1 cubic meter. Make models in three levels of detail (5/19/92). - When you die, you cannot reconstitute (6/23/92).

DECISION 12: IST will assign host ID #'s to everyone (4/10/92).

DECISION 13: Hit assessment is up to each simulator (4/10/92). IST has access to the SIMNET damage models. IST feels that weapons models should be uniformly utilized in the demonstration. If they are not used uniformly, then one simulator may get a kill for a weapon when another simulator does not for identical conditions.

SIMNET uses 30 degree sectors around a vehicles azimuth to compute hit or kill probabilities given a weapon type. Elevation is not considered (as far as can be determined by IST). This type of method is appropriate for ground vehicles, but not as realistic for air vehicles. However, adjusting the hit and kill probabilities can result in an acceptable portrayal of weapon effects. The

SIMNET method will be explained on 5/19/92 with a request for participants to approve or disprove the method used (5/6/92).

IST will create a matrix delineating if a weapon has an effect on an entity. The extent of the effect will be up to the receiving entity per the DIS standard for Detonation (5/30/92). Participants will use the default values in the hit/kill matrix supplied by IST unless they have their own matrix. (6/23/92) See ACTION Items 13, 18, and 23 (5/6/92).

DECISION 14: Damage models (i.e. hole in a/c wing) will not be considered (4/10/92).

DECISION 15: Next meeting: May 19th (4/10/92) Discuss: - model sheets- assignment of PDU fields - network progress (UDP/IP) - possible scenarios

DECISION 16: IST will work with NTSC to learn about UDP/IP for testbed conversion. If IST is unable to convert testbed in time for deadline on test stream data, NTSC will create test streams for participants. IST will handle the distribution of the test streams, whether generated by NTSC or IST (4/10/92).

DECISION 17: A decision was reached to use IP broadcast during the demonstration.

DECISION 18: IST will provide three levels of detail for the models to allow visual representation by various IG vendors in various degrees of fidelity (6/1/92).

DECISION 19: Any non-DIS traffic must be point-to-point to preclude any non-network traffic (5/19/92). Non-DIS traffic will be allowed on the network but must be transmitted point-to-point. IST will test for point-to-point transmission during interactive testing.

Participants must expect to see ARP requests and respond to the ARP if the participant's simulator generates non-DIS traffic. Testing will include generating/responding to an ARP request (6/23/92).

DECISION 20: UDP port 3000 will be used in the exercise (5/19/92).

DECISION 21: UDP/IP, TCP/IP, and SIMNET Association Protocol have been under evaluation at IST. UDP/IP will be used. Systems integration could be a problem (4/22/92) if participants are not familiar with the inner workings of UDP/IP. UDP/IP was under evaluation at IST. NTSC test streams have been determined not to be appropriate for I/ITSEC participants (4/22/92). Therefore, NTSC will not distribute the test streams (5/19/92). A protocol translator and a portable stealth will be procured by IST for the demonstration to assist software debug.

IST will create a network interface for UDP/IP, modify its PC based data logger for UDP/IP, create tools to perform DIS <-> SIMNET conversion (by aligning data structures and bridging misaligned or non-aligned elements), and modify its Computer Generated Forces Testbed to be compatible with UDP/IP (5/6/92).

Based on developments at IST (reported previously), IST feels confident about supporting a UDP/IP and Ethernet implementation for the demonstration. The specific UDP/IP features to be utilized are currently being investigated by IST. IST will also continue to investigate performance related issues of UDP/IP. As issues arise, they will be reported under separate ACTION ITEMS/DECISIONS.

The following paper represents IST's assumptions regarding UDP/IP (5/14/92):

UDP/IP Requirements and Specifications
for
I/ITSEC Interoperability Participants

Participants will be given their IP addresses on arrival at I/ITSEC. Those having multiple machines will be accommodated. IST requests that all participants having multiple machines connect each machine directly to the showroom LAN. Because addresses will not be available until I/ITSEC the participants are expected to be able to configure their machines at that time.

As of this writing (May 14, 1992), the LAN protocol is still open. We expect to resolve this by selecting Ethernet or 802.3 at the May 19 meeting at IST (Ethernet has been selected (6/23/92).

If any inter-participant messages must be put on the LAN during demonstrations they should be point-to-point if possible and, if that is not possible, multicast. Broadcasted inter-participant traffic should be avoided if at all possible.

Legitimate simulation traffic, and only such traffic, is to be directed to UDP port 3000 (decimal) using IP broadcast. IST emphasizes that inter-participant traffic, unless point to point, does not use this port. For inter-participant traffic, other than standard Unix services (defined in RFC 1060 -- Assigned numbers), participants should allow port configuration. At I/ITSEC IST recommends participants use ports 3xxx, with xxx matching one of their IP host addresses.

IST makes no recommendations for the UDP source port (the UDP source port is defined, in RFC 768 - User Datagram Protocol, as an optional field). IST also makes no recommendation as to whether the UDP optional checksum is computed or is sent as zero (see RFC 768).

Because simulation PDUs do not require IP fragmentation, there should be no fragmented IP traffic to UDP port 3000. Because all simulation packets are broadcast, no ARP requests are expected relating to the simulation proper. Participants may choose to ignore ARP requests and ICMP packets and participants are not required to generate either.

The following represents information concerning the physical network to support the I/ITSEC Demonstration:

IST has prepared a detailed network layout for I/ITSEC and is coordinating with the I/ITSEC facilities group regarding cable layout. Gamini Bulumulle at IST has copies of the layout. Thin coaxial will be the physical connection used in the I/ITSEC demo (5/19/92). IST will supply the cable, repeaters and T-connections for the I/ITSEC demonstration (6/23/92). IST has received information from Motorola regarding wireless Ethernet. As the participants are identified, IST will evaluate this system for suitability for I/ITSEC (4/22/92).

A decision was reached (5/19/92) not to use a wireless LAN for the I/ITSEC demonstration. This decision was based upon a study and recommendation by IST. IST has determined that the time required for tuning the system for the unique showroom configuration may be excessive. Tuning could be required for dead zones, to reduce overlapping coverage areas, and to account for EMI from other simulators. Vendors wishing to use wireless Ethernet can use the IST provided backbone to demonstrate performance (5/6/92). The Physical Layer protocol will be Ethernet not IEEE 802.3 (CSMA/CD). This closes ACTION items 2, 4, 7, 19, 29, 30, and 31.

DECISION 22: The next meeting (third) on the I/ITSEC demo will be held on June 23, 1992 at IST (5/19/92).

DECISION 23: A tutorial on SIF will be held on June 24, 1992 at IST (5/19/92).

DECISION 24: No new icon models will be allowed after June 23, 1992. (6/23/92) IST has received a complete list of models. The degree of articulation required will be requested of participants (Shen) (5/11/92) by 5/19/92. No weapon attachments to the entities as articulated parameters will be used (5/19/92). David Shen/IST will provide all participants a list of entity models and their providers by June 5th. This closes ACTION item 5.

DECISION 25: Interactive testing will be conducted using 1-800 dial up lines, no 56kbps service. The reason is that to date, no organization has indicated a willingness to fund new 56kbps service at their organization. Therefore, interactive checkout of interoperability is limited to commercial telephone service. This decision limits the number of entities which can simultaneously experiment with interactive simulation prior to I/ITSEC.

IST intends to install two lines with 800 service (date currently unknown) and use 9600 baud modems for interactive networking experimentation. The scenarios for I/ITSEC will be developed in a tiered approach where the number of participants can grow if the network can support the number of entities desired. Experimentation can occur during off hours at I/ITSEC (5/11/92). This closes ACTION items 8 and 34. (6/23/92)

DECISION 26: All testing will be conducted by IST, no third party testing will be required. (6/23/92)

DECISION 27: To ensure a win-win scenario, all participants will be on the same side (friendly) and will fight SAF (foe) generated by IDA, BBN, and IST. The SAF will be "targets" with limited fighting capability. (6/23/92)

DECISION 28: Two formal exercises will be conducted at I/ITSEC: Monday morning during the opening plenary and Tuesday night before the banquet. An informal exercise to test experimental PDUs (e.g., Emitter PDU) will take place on Wednesday morning. (6/23/92)

DECISION 29: IST will prepare and maintain a list of Action Items and Decisions. This closes Action 1. (4/22/92)

DECISION 30: Testing results of individual companies will be kept confidential. (6/23/92)

DECISION 31: IST will assign site and host id numbers before I/ITSEC so that participants can make the appropriate changes to their simulator software. (6/23/92)

DECISION 32: IST will generate a SAF helicopter and a carrier for the formal exercises. (6/23/92)

DECISION 33: Coordinates will be expressed using WGS 84. Numerous papers and opinions have been expressed concerning the use of a non-flat earth. Potential problems include differences in simulated position versus position in the visual system as well as accumulated round off and truncation errors. IST will develop an algorithm (after obtaining a group of algorithms from TEC) for converting from various flat earth representations to WGS 84.

Brian Goldiez has the most complete set of papers on issues, concerns and algorithms related to this topic. See ACTION item 24 (6/23/92).

DECISION 34: The next meeting will be held at IST on July 29, 1992 starting at 9:00 am. (6/23/92)

DECISION 35: IST (David Shen) has created a list of model types in accordance with the DIS standard. This list also identifies the degree of articulation for specific model types. This completes ACTION item 6. (6/23/92)

DECISION 36: IST will create a Test Procedures to determine simulator compliance with the portions of DIS applicable to the I/ITSEC demonstration. See ACTION 21 (7/10/92). The first draft of the test procedures will be released early during the week of 16 June 1992 (6/4/92).

Test Procedures have been released. They will be finalized by IST before the July 29 meeting. Finalization will include coordination with participating organizations, establishing criteria, and additional technical details. Coordination will ensure that each participant is comfortable with the scope of testing.

Participants can recommend the addition or deletion of specific tests. Criteria will help establish acceptable ranges for cumulative tests. This will assist participants in addressing and prioritizing success or failure of particular tests. Criteria will also help establish minimum criteria for participation in various types of I/ITSEC demonstrations.

Additional technical detail will include interactive testing (limited scenario development), the creation of tolerances for values (e.g., coordinate transform positional and angular tolerances), network stress testing (through disks distributed to participants, or the use of the IST SAF, or through some form of interactive testing). (6/23/92).

The second draft of the Test Procedures, dated 7/10/92 will be released during the week of 7/13/92 (7/10/92).

DECISION 37: A compromise was reached that was satisfactory to all visual vendors. Within a 300 square kilometer area several ground rules will apply. First, participants are requested to use the polygonal 2851 SIF format to match polygon dimensions to within one meter. Secondly, the 300 square kilometer area will be the only area where ground forces will be present and the only area where ordnance may be delivered to the ground.

Within the other 9700 square kilometer area vendors may use either the gridded or polygonal representation of terrain. (Lower left is FQ 5073, upper left is FQ 5083, lower right is FQ 8073, and the upper right is FQ 8083).

(7/29/92) STATUS: OPEN. (8/20/92)

DECISION 38: The following was the agreement reached regarding ground rules for participating on the network at I/ITSEC. IST (Margaret Loper) will develop a detailed plan to bring the network on line and bring participants onto the network. Participants who take part in the integration and testing activities in San Antonio starting on October 26 will receive priority in integrating their systems at I/ITSEC. There is a 30 hour window between the time when the Exhibit Hall opens and when the

Plenary session starts. The time is to be allocated as follows:

FIRST TEN HOURS. The network will be configured and participants will set up their equipment and establish a network capability similar to the capability established during the week of October 26. This time could be expanded (but will be less than 20 hours) if setup or reconfiguration difficulties are encountered.

SECOND TEN HOURS. Participants unable to take part in the activities of October 26 will be afforded an opportunity to get on the network. The baseline network established, above, will not be compromised. That is, if someone is unable to get on the network (with sufficient help from participants) or causes other problems which impact other participants; that participant's simulator will be rejected for participation and the participant will be put into the bottom of the queue. Each participant will be given a one hour block to establish connection to the network. It is possible that the baseline network established in the first ten hour period may be broken into sub-nets if there are more than 2 organizations needing to get onto the network. A lottery will be held by IST if there are more than 2 organizations needing to get on the network during this time period.

A participant will be denied access to the network for the Plenary Demonstration if they are unable to connect to the network or they adversely affect other simulators on the network.

PLEASE NOTE: There is a chance this time period could be greater than or less than 10 hours. Past experience indicates a small probability that the time period will be greater than 10 hours.

THIRD TEN HOURS. This period will be devoted to rehearsal and fine tuning of the Plenary demonstration.

If an organization, not participating in the October 26 integration period, is unable to participate in the Plenary Demonstration, they will be afforded an opportunity to establish a network connection and not adversely affect other simulators on the network during the course of the I/ITSEC. This activity will occur on a non-

interference basis with other network activities. IST will provide reasonable support. Connection without adverse impact will be required for the demonstration to be conducted at the Cocktail hour on Tuesday evening.

Dan Mullally strongly suggested that companies that cannot attend the rehearsal send an observer so that they can "catch up" with those all ready there. Hand walkie-talkies will not be practical for simulator operators. Dan Mullally will talk to the contractor about the possibility of headsets or some other type of communication system. Maps were mailed on the 10th of August. Detailed plenary and banquet scenarios will be available on Oct. 26. Free play will be allowed during rehearsals. A list of items that will be used as targets is needed from each participant. The Stealth screen should be up for free play (8/20/92).

DECISION 39: The next meeting is scheduled to be held on Wed. 23 Sept. 92 during the evening at the scheduled DIS workshop at the Holiday Inn on International Drive in Orlando (8/20/92).

DECISION 40: The network is public. All participants can tap the network to collect data (8/20/92).

DECISION 41: IST will provide only one Ethernet BNC interface per booth (see DECISION 21) (8/20/92).

DECISION 42: Relative time stamps will be used for PDU's on the I/ITSEC network. This decision was made several months ago, but was not recorded (10/8/92).

ACTIONS

ACTION 1: Create list of Action Item's & decisions & send out (4/10/92).

STATUS: COMPLETE. See Decision 29. (4/22/92)

ACTION 2: Investigate wireless E-NET (Ralph Whitney get data to IST) (4/10/92).

STATUS: COMPLETE See Decision 21. (5/6/92)

ACTION 3: Identify participants for the I/ITSEC Demonstration by 4/17 (4/10/92).

STATUS: IST has identified the following organizations who will participate in the demo:

<u>LORAL</u>
<u>IST</u>
<u>TSI</u>
<u>CAE-LINK</u>
<u>NTSC</u>
<u>BBN</u>

Several other organizations are awaiting management approval. (4/22/92). Additional organizations now include:

<u>HUGHES</u>
<u>ARMSTRONG LABS.</u>
<u>IDA</u>
<u>GENERAL ELECTRIC</u>

Additional organizations now include:

<u>Lockheed-Sanders</u>
<u>Grumman</u>
<u>IBM</u>
<u>Reflectone</u>
<u>Star Technologies</u>
<u>Motorola</u>
<u>NRaD</u>
<u>Gen. Dynamics Land Systems</u>
<u>Gen. Dynamics, Ft. Worth Div.</u>
<u>Concurrent Computer</u>

Additional Organizations now include (10/13/92)

<u>STRICOM</u>
<u>USAF ASD</u>
<u>DMSO</u>
<u>Silicon Graphics (MAK)</u>
<u>PRC</u>
<u>McDonnell Douglass Training Systems</u>
<u>Rockwell International Space Systems Div</u>

ACTION 4: Select physical n/w layer (4/10/92).

STATUS: COMPLETE. See Decision 21. (5/19/92)

ACTION 5: Notify IST of all new models needed by April 30. Conversion of new models will begin June 1 at IST (Curt Lisle). IST will convert models on a first come, first serve basis, subject to resource availability (4/10/92).

STATUS: COMPLETE. See Decision 24. (6/23/92)

ACTION 6: "Model form" to be generated by IST and distributed to group next week. Due back to IST by end of

month (model - # articulated parts - weapons/munitions). A description of articulated parts, including their connectivity will be supplied by the organization providing the model data (4/10/92).

STATUS: COMPLETE. See Decision 35. (6/23/92)

ACTION 7: Rules(4/10/92) -IST will assess the feasibility of implementing UDP/IP with the help of NTSC

- NTSC will not distribute test streams (if they have to generate them) - IST will distribute

- Protocol translator (TSI) turned on: May 1 delivered: July 31 - $8K board with sw modules - SIMNET - DIS (now) - SIMNET/Association Protocol - DIS/UDP-IP (future)

STATUS: COMPLETE. See Decision 21. (5/19/92)

ACTION 8: Companies must indicate their network bandwidth needs for testing willingness to pay for 56kbps lines on their end (Contact Margaret Loper). This information is to be provided no later than 4/17 (4/10/92).

STATUS: CLOSED. See DECISION 25. (6/23/92)

ACTION 9: BBN will provide IST with S1000 and MC compiled software of new terrain database (4/10/92).

STATUS: COMPLETE (5/17/92).

ACTION 10: Motorola and Margaret Loper will determine BW capabilities on show floor net (4/10/92).

STATUS: Current activity has uncovered several parameters which will influence bandwidth on the show floor. First, is 10 Mbps from Ethernet. Ethernet is not expected to be the limiting factor. Second is any interface hardware between the network and the host computer. Third is particular implementation of UDP/IP. Experience from some companies indicated a 200-300 packet per second rate on Sun's UDP/IP.

Fourth is the simulator math model limitations on tracking moving models or other DIS related parameters. Fifth is the visual system limitations on dynamic coordinate sets or other DIS related

parameters. Sixth is the limitation noted elsewhere on interactive testing using commercial telephone linkage and 9600 baud modems.
IST is investigating each aspect noted above to arrive at limiting factors for demonstrating DIS (5/11/92). Margaret Loper presented updated results 6/23/92. The results follow:

In order to complete the BW analysis, a questionnaire (see ACTION 33) was distributed to participants surveying simulator processing capabilities. Participants were asked to identify the following processing constraints: interface hardware (in PDUs/sec), communication protocols (in PDUs/sec), simulator math models (in # of entities), and IGs (in # of dynamic coordinate systems). The following ranges were obtained:

```
+-----------------------+
|     IG Filtering      |          6 - 800 entities
+-----------------------+
          ^
          |
+-----------------------+
| Simulator Math Models |          6 - 800 entities
+-----------------------+
          ^
          |
+-----------------------+
|     Communication     |
|  Protocols (UDP/IP)   |           15 - 500
+-----------------------+           PDUs/sec
          ^            * not all participants
          |              responded to this
          |              question
+-----------------------+
|  Interface Hardware   |           30 - 2000
+-----------------------+           PDUs/sec
          ^
          |
-------------------------------------------------------------

                Ethernet  (10Mbps)
```

From the BW program developed by Grumman, the following data was calculated:

```
Entity Type and Number   ->   100 tanks, 11 aircraft, 1 ship
Low Rate (no conflict)   ->   55 kbps or 22 PDUs/sec
High Rate (all conflict) ->   800 kbps or 311 PDUs/sec
```

From initial calculations we can make the following assertions:

1) 112 entities will not exceed Ethernet (10Mbps).
2) The interface hardware and UDP/IP processing constraints will present the biggest problem in determining the number of entities participating in the demo. The trade-off is low-performance vs. high-performance simulators. Scenario development will not solve this problem.
3) Simulator math models and IG constraints will be secondary problems and may be alleviated through filtering and prioritization. If not, scenario development can strategically place entities so as to pre-filter for those simulators not capable.
4) If all entities are in low or no conflict, minimal problems should occur at simulator hosts.
5) If all entities are in high conflict, major problems will occur with low-performance simulators. A rate of 311 PDUs/sec will overwhelm the lower bounds of 30 and 15 PDUs/sec for hw interface and UDP/IP, respectively. (6/29/92).

ACTION 11: IST will get polygon models from NPS. All models for this demonstration will be distributed by IST or PRC (4/10/92).

STATUS: COMPLETE. See DECISION 7. (6/23/92)

ACTION 12: IST will produce a matrix of weapon/munition vs. platform and assign probability of kills. We will distribute next month (May). **((See SIMNET vehicle simulator documents because some are already done)) (4/10/92)

STATUS: COMPLETE. See DECISION 13 (5/30/92).

ACTION 12A: IST offered to produce a DIS version of the ISF testbed which used BBN's AP or else straight IEEE-802.3 frames. IST promised to look into implementing a minimal UDP/IP interface for the testbed. No firm dates were specified (4/10/92).

STATUS: CLOSED. IST will implement UDP/IP (4/27/92). Item was modified to 12A to avoid duplication with other Action Item 12 (5/30/92). See DECISION 21 (6/23/92).

ACTION 13: IST will assess the number of entities which can be simultaneously demonstrated at I/ITSEC. Limits

will be based upon the lesser number of CIG moving models, network bandwidth, or simulator limitations (4/10/92).

STATUS: CLOSED. This matter is covered in Action Item 10.

ACTION 14: There is a need for IST to check the draft standard to see if the entity codes that have been provided in Appendix H2 will support the selected models. IS will define numbers for undefined entities (4/10/92).

STATUS: CLOSED. DECISION 24 closes this item (6/23/92). As items are submitted, they are checked for Appendix H2 coverage. Those items which are not covered are assigned an entity code (5/6/92).

ACTION 15: PRC will get SIF format or ASCII format to the rest of the group by July 15. If IST is overloaded, participants will be responsible to get SIF or ASCII format to the rest of the participants by 15 July (4/10/92). Modify this Action Item to read, "Regarding moving models, PRC will get SIF format to the rest of the group by July 15. If IST is overloaded, participants will be responsible to get SIF or ASCII formats to the rest of participants by July 15. If PRC receives an ASCII model, they will provide it to IST "as is".

The entire Terrain Data Base will be available August 15" (4/15/92). A SIF sample has been prepared and is available. The Hunter-Liggett area is currently being validated by PRC. The validation will not be completed until the latter part of August. Therefore, distribution of the 2851 SIF data base of Hunter-Liggett will not occur until the end of August. The period for testing will be reduced to September and October due to data base delays and the need for participants to tailor the testing document (7/29/92).

PRC has made distribution of and updates to SIF format. Algorithms for map conversions were distributed by Huat Ng. A decision was made to freeze the current version of the database, due out during the week of 25 Sept. 1992 (9/23/92).

STATUS: CLOSED. (9/23/92)

ACTION 16: TSI and Loral are to get back to IST by 17 April concerning the use of the PDU translator to do testing of DIS at IST using the SIMNET equipment in the IST lab (4/10/92).

STATUS: CLOSED. Translator does not currently support UDP/IP. Currently reviewing necessary effort to accommodate UDP/IP. (4/22/92)

ACTION 17: IDA will work with IST on integrating scenario generation with testing in the schedule. IDA will supply large screen display and display driver from network for I/ITSEC (4/10/92). Final floor plan and layout info not available (7/29/92). IDA discussed set-up of large screen display. IDA will provide access and availability schedule on a sign-up basis during the open time. Margaret Loper has openings in the sign-up sheet for informal (freeplay) exercises (see ACTION 37). Openings for freeplay exercises are still available (9/23/92).

STATUS: OPEN (9/23/92).

ACTION 18: For display of damaged appearance, model developers (PRC or IST) will need to develop damaged version of various vehicles (4/10/92).

STATUS: CLOSED. See DECISION 7 (6/23/92).

ACTION 19: IST (M. Craft) will create a list of assumptions for participants regarding the use of UDP/IP for the 5/19 meeting (5/6/92).

STATUS: CLOSED. See DECISION 21 (6/5/92).

ACTION 20: IST (Goldiez) will arrange a colloquium for parties interested in learning more about UDP/IP (5/6/92). A UDP/IP colloquium will be held on August 21 for 2 hours in the morning. More info will be sent out at a later date. Contact Michael Craft (7/29/92). The UDP/IP colloquium was filled to capacity. This completes ACTION 20.

STATUS: CLOSED (8/20/92).

ACTION 21: IST will determine and announce the date of completion on test procedures by June 5th (5/19/92).(7/29/92).

STATUS: CLOSED. See DECISION 36 (7/10/92).

ACTION 22: IST will accumulate and analyze network traffic collected during the I/ITSEC demo (5/19/92). Gamini Bulumulle discussed the capabilities of the network analyzer (8/20/92). Analysis of the network will be made during and after I/ITSEC (9/23/92).

STATUS: OPEN (9/23/92)

ACTION 23: IST will provide and distribute a hit/kill matrix by weapon/target by the end of May. This matrix will be used for kill probability determination for use in the I/ITSEC demo (5/19/92).

STATUS: CLOSED. See DECISION 13.

ACTION 24: Participants should return comments regarding geocentricity paper by Brian Goldiez by June 5th (5/19/92).

STATUS: IST will develop the algorithms for coordinate transformations and present them to the group and to TEC. See DECISION 33 (6/23/92).

IST presented its analysis and recommendation for coordinate transformation algorithms between geocentric, geodetic, and topocentric coordinate systems. A method using Newton-Raphson's algorithm was suggested. The methodology and rationale is described in IST-TR-92-24 entitled "Interconversions Between Different Coordinate Systems", dated July 1992.

IST asked that the algorithms recommended in this report be approved for use in describing coordinate transformations. I/ITSEC participants were given until August 12, 1992 to comment on the algorithm recommendation. If no comments are received, or are properly dispositioned, the Newton-Raphson algorithms will be used (7/29/92). Discussions on geocentric coordinate system remains open (9/23/92).

STATUS: OPEN. (9/23/92)

ACTION 25: IST will find guidelines for videotaping for individual companies (5/19/92). IDA spoke on the value of video-taping. Demo players were asked to respond by 9/15/92 on each company providing 3-5 minutes on 3/4" or 1/2" tape. This will be used as a DIS promo (8/20/92). During a discussion on

video-taping of the DIS demo, the U.S. Army, STRICOM announced the decision to support the cost to videotape during I/ITSEC. The demonstrators would have access to review the tapes (9/23/92).

STATUS: OPEN. (9/23/92)

ACTION 26: IST will provide models through Internet when available (5/19/92).

STATUS: Pending return of models from PRC (6/1/92).

ACTION 27: IST will provide information regarding special effects visualization, i.e. muzzle flash, explosion, etc..

STATUS: COMPLETE. See DECISION 7 (6/23/92).

ACTION 28: A list of minimum hardware specifications must be provided to all participants for the IST developed SAF (5/19/92). IST provided specifications to all who attended the demo meeting on 5/19/92. Loral (ADST contractor) distributed the IST developed SAF to all I/ITSEC demo players (see ACTION 49) (8/20/92).

STATUS: CLOSED (8/20/92).

ACTION 29: Participants will decide on using either Ethernet or 802.3 and return decision to IST no later than June 5, 1992 (5/19/92).

STATUS: CLOSED. See Decision 21. (6/23/92)

ACTION 30: IST will provide cables, repeaters, and T-connections for the demonstration (5/19/92).

STATUS: COMPLETE. See Decision 21 (6/23/92).

ACTION 31: IST will provide a detailed network layout (5/19/92).

STATUS: COMPLETE. See Decision 21 (6/23/92).

ACTION 32: A request was made by Dan Mullally/IST to develop and return by June 5, 1992 the scenario outlines provided at the 5/19/92 I/ITSEC demo meeting (5/19/92).

STATUS: Detailed sample scenarios will be created by IST by July 15, 1992. The scenarios will separately support testing and the I/ITSEC demonstration. (6/23/92). A demonstration vuegraph outline form was presented to all participants to complete and return. Time constraints during the pre-banquet demo will require that the scenarios be shortened to allow concurrent land, sea, and air play. Detailed scenario information will be distributed to all participants A.S.A.P. (7/29/92).

Detailed scenarios will be created based on the outlines previously distributed (8/20/92). Draft plenary and banquet demonstration scenarios were distributed for review. Attendees were broken up into air, land, and sea sub-groups to review and provide input to modify the draft scenarios. Attendees were asked to submit individual and subgroup recommendations for modifications (9/23/92).

STATUS: OPEN. (9/23/92)

ACTION 33: Margaret Loper will prepare and distribute an entity survey form to determine network bandwidth equipment. Forms should be returned to IST no later than June 1, 1992. Forms faxed 5/20/92. She will present at the next demo meeting scheduled for June 23, 1992 (5/19/92). The surveys completed by participants indicate a maximum of 235 entities can be generated by the participating simulators.

However, the Physical interface hardware and UDP/IP processing constraints will limit the number of entities that can actually participate. This analysis is on-going under ACTION 10 (6/23/92). Analysis is ongoing. Margaret Loper could identify the upper bounds but could give no information on specific scenarios (7/29/92). Analysis continues in view of the changing players and scenarios (9/23/92).

STATUS: OPEN. (9/23/92)

ACTION 34: IST will investigate fractional 56 kbps lines and provide information at the next meeting on the I/ITSEC demo (5/19/92).

STATUS: CLOSED. See DECISION 25. (6/23/92)

ACTION 36: IST will place an announcement about the I/ITSEC demo in the CBD. (6/23/92) CBD announcement request passed to STRICOM for action.

STATUS: CLOSED. (7/29/92)

ACTION 37: Margaret Loper will generate a schedule of formal and informal exercises for participants. A sign-up sheet for scheduling informal (including freeplay) exercises will be developed and distributed to participants by July 1. Responses are due back by July 15 (6/23/92). Free play time slots are still open (7/29/92). A list of items that will be used for targets is needed from each participant. Free play will be allowed between all demo players on a sign-up basis. IDA will make the large screen available during these freeplay exercises.IST will develop specific uses and demonstrations for the network at I/ITSEC. IST will then attempt to get participants involved in utilizing the network. Only when participants have indicated interest in utilizing the network (either with IST or separately) will IST attempt to assist in defining experiments (8/20/92). A discussion on the availability of the large screen for freeplay demonstrations was held. Availability will be determined through coordination with the I/ITSEC special events committee by Bruce McDonald, IST. Time slots for demos are still available (9/23/92).

STATUS: OPEN. (9/23/92)

ACTION 38: Traffic on the network is divided into two types: DIS PDUs, which all participants must accept and respond to and Other Data, which participants should expect to see but require no response. Margaret Loper will send a questionnaire asking participants to define the Other data they expect to put on the net (e.g., Emitter PDU) by July 1. Responses are due back by July 15. A composite list of DIS and Other data will be sent to participants by July 24 (6/23/92). Action remains open due to limited responses to the survey (7/29/92). (9/23/92).

STATUS: OPEN. (9/23/92)

ACTION 39: IST will investigate integrating the SLIP protocols into the ISF testbed. (6/23/92) There are three methods to allow connection to IST for testing. One is to use lease lines (T-1 with CSU/DSU). A second method is to use routers and the third

method is to use SLIP (Serial Line IP) or PPP (Point to Point Protocol). Lease lines are not cost effective for IST and the lead time for procurement and installation makes them impractical.

Routers are not practical because their internal data conversion routines are proprietary. Therefore, if one uses a router, they must have the same router on each end of the connection. Such an arrangement is not practical or cost effective for this demonstration. The third method is to use interface software to support testing. SLIP is available at no additional cost on several computer systems (e.g., SUN).

SLIP as a stand alone product (e.g., DOS version) is available for purchase. PPP is a new product with higher performance than SLIP. However, the availability of PPP is currently limited to DOS machines (7/27/92). IST received the necessary hardware (NetBlazer, 2 modems) and is in the process of networking with the Sun and Motorola networks. At the same time IST is trying to install SLIP software (DOS version) in a PC and connect it to the network using a serial line (RS232) (7/16/92).

Based on the June 1992 Interoperability meeting at IST, the third method (interface software) will be used for the I/ITSEC demonstration and the DIS testbed at IST. The hardware configuration at IST will support SLIP or PPP. IST will demonstrate the use of SLIP and most of the testing set-up on 7/29/92.

STATUS: CLOSED. (7/29/92)

ACTION 40: IST will look into the price difference and vendor interoperability of 9.6 and 19.2 modems (6/23/92). Vendor interoperability requirements: Any modem which is fully compatible with the CCITT V.32 specifications. Price difference : Most of the asynchronous modems runs from 300bps to 38.4kbps. The modems listed below can accommodate our 19.2kbps requirements.

TELEBIT T3000 modem - $645.00 (used in our application). Motorola V.3225 Data Modem - $574.00 Black Box has various types of modems. Modem 3242-XB - $795.0 Modem 32144 - $1395.00

STATUS: CLOSED. (8/20/92)

ACTION 41: IST will look into the price difference and vendor interoperability of 9.6 and 19.2 modems (6/23/92). Gamini Bulumulle announced the v.32 standard, price difference and vendor interoperability of the 9.6 and 19.2 modems.

STATUS: CLOSED. (7/29/92)

ACTION 42: IST will identify the location of walkie-talkies in all booths (6/23/92). Action remains open until all booth locations and participants are identified (7/29/92). A walkie-talkie will be assigned to each demo player booth. Martin Marietta has 12 voice activated radios available (8/20/92). Action remains open (9/23/92).

STATUS: OPEN. (9/23/92)

ACTION 43: Brian Goldiez will distribute a questionnaire on detailed simulator configurations by July 6. Responses from participants are due back by July 31. (6/23/92) Questionnaire will be distributed during the week of 7/13/92 (7/10/92). Detailed simulator configuration data is still pending from several demo players. All players were asked to complete and return data required, A.S.A.P. (8/20/92). (9/23/92).

STATUS: OPEN. (9/23/92)

ACTION 44: IST will develop a list of POC's from each company participating in the I/ITSEC demo. Brian asked all demo participants to provide him with a written statement of intent to participate in the I/ITSEC demo (7/29/92).

STATUS: COMPLETE. (8/20/92)

ACTION 45: A decision was made to determine if a space could be found in San Antonio, TX for a rehearsal by all participants in the week preceding I/ITSEC. All participants were asked to provide space, power, cooling and weight of their equipment. Arrangement to have equipment moved by USAF from rehearsal site to the convention center was also discussed.

The USAF will act as a POC to determine the availability of a rehearsal site in San Antonio during the week preceding I/ITSEC (7/29/92). Space

options were discussed with the option of a separate room in the convention center being the preference of all demo players. Requirements (size, weight, power, # of outlets); must have this info. to find adequate rehearsal site. If unsure, give estimate of worst possible case (i.e., maximum power, largest size, etc.). Want rehearsal to be up and running Wed., Oct. 26.

A lengthy discussion followed during which the benefit of having a rehearsal was debated. A way to prioritize those individuals who attend the rehearsal and those who do not was discussed. Brian Goldiez went over the decided method for rehearsal and testing:One week before I/ITSEC (Monday, Oct. 26), a facility previously secured for rehearsal and testing will be available to the participants. The first choice would be a place in the convention center (to minimize the move to the exhibition hall). A second choice would be a military facility close to the exhibition site. E&S is investigating the feasibility of using the convention facility (not the actual exhibit hall) starting on October 26.

Dennis is also investigating funds necessary to secure the facility if it is available. This action should be dispositioned by 8/28. IST (Bruce McDonald) should work with JMK to ensure I/ITSEC participants receive priority on moving our equipment into the Exhibit hall. JMK should be invited to attend the next meeting in September. The companies that show up for rehearsal will be tested one at a time and then matched up in groups. The testing will make sure that certain programs do not "crash" the network and will help the companies work out the "bugs" in their systems.

Each company must bring enough equipment so as to adequately represent the simulations they will be presenting in the regular conference. On Saturday, all those companies that are in rehearsal must be prepared to disconnect and move to the exhibition hall. The first ten hours will accommodate the rehearsal companies and establish connectivity. The second ten hour period will be for those companies who could not be there for rehearsal to see if they can get on the network without problems.

If they cannot get on the network, they cannot participate in the plenary. The third ten hour

period will be used for rehearsal and "fine tuning" for those participating in the plenary (8/20/92). A briefing and update on the demonstration times and locations was given by Dan Mullally and Mr. Keith Tanner of JMK associates:

a. Rehearsal location. The I/ITSEC Facilities Committee has secured the use of the Gallery Room in the San Antonio Convention Center. The Gallery Room has space for the demo players to set-up their minimum equipment configuration for the demo rehearsal.

b. Time of Arrival. The contractor will be prepared to handle heavy lifts on Monday 26 October 1992 from 0800 to 1100. A heavy lift is anything requiring a fork lift that cannot be hand carried or placed on a dolly. Time of delivery of heavy lifts after Monday can't be guaranteed by the convention contractor due to another show scheduled into the San Antonio Convention Center. The contractor will charge for the heavy lift movement.

c. Power Requirements. A new electrical contractor has been engaged for the San Antonio I/ITSEC convention. Forms for the electrical contractor (Harper -Wood) will be available at the 23 Sept. DIS Workshop meeting of the Demo Participants at the Holiday Inn, International Drive here in Orlando.

d. Rehearsal floor plan set-up: The set-up will be based on the actual I/ITSEC South Exhibit Hall floor plan to be used during the 2-5 Nov I/ITSEC. Gamini will provide tentative network floor plans at the 23 Sept meeting. Gamini will set up Ethernet network and individual spaces based on the sq. ft. requirements previously submitted.

e. Rehearsal Schedule:
Monday, 26 Oct 92: Arrive at Convention Center and set up rehearsal area in Gallery Room. Access for all hand carried and dolly cart carried equipment available from S. Alamo St. entrance. Electrical contractor on-site to provide pre-arranged power. Network Tests start as soon as possible.

Tuesday, 27 Oct 92: Network Tests continue. Appearance Tests and Scenario Testing will be scheduled ASAP based on Network test status.

Wednesday, 28 Oct 92: Rehearsal continues.

Thursday, 29 Oct 92: Rehearsal continues.

Friday, 30 Oct 92: Rehearsal continues. Lila Cockrell Theatre in the Convention Center available from Friday Morning for set-up. Friday Noon, South Exhibit Hall available for Booth set-up by rehearsal players.

Saturday, 31 Oct 92: 0900-1300 Ethernet will be laid out in South Exhibit Hall. Network Re-test begins at 1300.

Sunday, 1 Nov 92: Rehearsal continues. Exhibits open 1700-2000.

Monday, 2 Nov 92: Rehearsal continues. Interoperability Demo for Plenary session scheduled at 0930.

Tuesday, 2 Nov 92: Exhibit Hall opens 0900. Freeplay Demonstrations 1100-1800, Banquet Demonstration 1900-1920.

Wednesday, 4 Nov 92: Freeplay Demonstrations 0900-1200. Exhibit Hall Closes 1200.

At the DIS Demo meeting on 23 September all demo players were asked to provide final electrical, telephone, and heavy lift requirements to the Convention Contractor. The contractor will ask for the weight and cube of the heavy lift (Fork Lift) requirements.

Draft Final Scenarios will be presented at the 23 September Meeting. Please contact me at (407) 658 5023 voice, 5059 FAX on any networked simulator changes which will affect the scenarios (9/23/92).

STATUS: CLOSED. (9/23/92)

ACTION 46: A discussion on separating the initial presentation into an overview given by an Air Force general and a more specific briefing given by an appropriate presenter using canned or video augmented presentation along with live scenario play was held. Dan Mullally will report at the next scheduled meeting on this item (7/29/92). The plenary demonstration and presentation will be given by Lt.Gen. Rogers, J-7, interoperability (8/20/92).

STATUS: CLOSED. (8/20/92)

ACTION 47: A request to provide military maps to all participants of the Hunter-Liggett area is being looked into by Dan Mullally (7/29/92). Simnet maps of the Hunter-Liggett area were distributed to all players on 8/20/92. Additional 1:50,000 tactical maps of the Hunter-Liggett have been requested from the Army and will be distributed when received (8/20/92). A decision was made that the Army, (STRICOM) would provide maps to all participants (9/23/92).

STATUS: OPEN. (9/23/92)

ACTION 48: Visual system data bases were discussed during the (7/29/92) meeting. KOAN explained the formats being provided for P2851 SIF. They explained that the source of the Hunter-Liggett gaming area for I/ITSEC is the BBN data base used in SIMNET. The data processed into 2851 SIF using a formatter that converts from the BBN S1000 modeling system to a 2851 format. The resulting SIF is converted from UTM to Geodetic and is also formatted to be consistent with the 2851 specification.

KOAN will provide participants with the algorithm used to convert from UTM to Geodetic. KOAN also agreed to look into the possibility of PRC generating maps from the data base and report to the group at the next meeting on this possibility. Two forms of SIF will be provided; a polygonal representation and a gridded model. There was quite a bit of discussion on which version one should try to match. The non-BBN vendors had concerns about using the polygonal model as a baseline to match their own terrain models. The reasons for the concern were the lack of specific vendor tools for converting someone else's (including 2851) polygonal models to a data base compatible with the vendors image generator, the amount of time and money necessary to make the conversion, and the performance implications of using a data base which was originally optimized and derived from a specific system (i.e., BBN) which is different from everyone else's system.

It should be noted, in defense of BBN, that this problem would arise if any other vendor's data base was used as a source. KOAN will provide algorithms and maps of the terrain data base (7/29/92). KOAN reported that the culture data base was not ready

yet. The complete data base will be ready next week. KOAN will provide map and conversion algorithms (UTM to geodetic) (8/20/92).

STATUS: OPEN. (8/20/92)

ACTION 49: The IST CGF System will be present in the I/ITSEC Interop Demo in three different roles. (1) in support of pre-I/ITSEC testing (2) as support at the I/ITSEC demonstration (3) as an active participant in one or more of the I/ITSEC scenarios

STATUS: A minimum CGF workstation consists of two IBM-compatible 386 or 486 PCs. One of the PCs runs the entity simulations (the "simulator" and the other provides an operator interface (the "OI"). Additional Simulators or OIs may be added to the configuration as needed. Both the Simulator and OI are connected to the Ethernet network, and they communicate with each other over the network, exchanging non-standard PDUs. The software is written in ANSI C. A single 2 PC CGF workstation can support up to approximately 12 simulated entities. The system has been tested with as many as 30 external entities on the network; we suspect that the system would have difficulty dealing with more external network traffic than that.

The current version of the CGF system uses either the SIMNET or the DIS protocol, selected at compile-time. During the period leading up to the I/ITSEC demo, participants may wish to connect to IST's DIS network and test specific network interactions, such as fire and detonation sequences, collisions, etc. IST will use the CGF system to provide the vehicles and other entities needed for these tests. Such tests are at the discretion of the participants; they should be arranged in advance. In this role, the CGF system will exemplify the DIS protocol, as known and implemented at IST.

Support at the I/ITSEC demonstration: The IST CGF System will act in support at the Interop Demo, providing two functions, an LHD and Targets. For the benefit of those participants and scenarios that require a helicopter carrier, the IST CGF System will generate a LHD (Wasp class) helicopter carrier. The representation will be extremely simple, as the LHD is being generated primarily to provide a landing site for the benefit of RWA simulators.

Once created, the LHD will move steadily along a simple racetrack path at a steady speed of 20 knots; see the diagram below. While turning the LHD will heel approximately 10 degrees to port (to the outside of the turn). The transitions from 0 degrees to 10 degrees and from 10 degrees to 0 degrees will take approximately 10 seconds. The LHD has no other behaviors or capabilities; specifically, it will not respond to incoming Detonation PDUs.

The IST CGF System will provide target entities so that other participants can have a predictable set of targets for their demonstrations. Target entities, or targets, will appear to be ordinary simulation entities (i.e. their Entity State PDUs will be normal) in all respects except for their behavior.

Targets can be created at any location in the scenario terrain. They can be assigned a route, which may be either an open path or a closed loop. Once created, a target will follow its assigned path. Upon reaching the end of a closed loop path, the target will repeat the path indefinitely. A target on an open path will stop at the end of that path.

Targets will, of course, react to incoming Detonation PDUs as specified in the 'Matrix of Munition Type x Entity Type' prepared by IST. Once destroyed, the target will go through the normal SIMNET burn sequence, culminating in the 'blackened hulk' stage (this sequence takes almost 30 minutes in SIMNET, but will be reduced to about 6 minutes for a target). After 2 minutes as a blackened hulk, a destroyed target will disappear from the battlefield. One minute later, the target will be reconstituted at its creation point and again begin following its path.

Targets will not react to events in the simulation around them, i.e. they will not attempt to avoid hostile entities. They will not fire their weapons. Defining a target or set of targets requires advance preparation to fine tune the positions, routes, etc. Demo participants who would like to use IST provided targets should arrange for that support in advance. IST (CGF Group) will provide the following air targets:

A-10's Su-25's Havoc's Apache's

The models provided will be limited in quantity and will exhibit very simple behavior (a simple racetrack). Questions:
(1) Is the LHD speed of 20 knots acceptable to its users?
(2) Does anyone need to attack the LHD?
(3) Do the burn and reappear times for targets seem suitable?
(4) Should targets detect and process collisions?
(5) Note that current plans provide for only ground vehicles as targets. Are aircraft or ships needed as targets by any participants?

Because no response was received from the demo players, this item is closed (9/23/92).

STATUS: CLOSED. (9/23/92)

ACTION 50: IST will update its Test Procedures document in approximately 2-3 weeks. IST will disposition comments received prior to 8/20/92 by either incorporation into a revised document or by explanation to the author. All substantive comments received prior to 8/18/92 were discussed during the meeting on 8/20/92. Additional comments were received on 8/18/92, but not discussed or dispositioned, on 8/20/92. Additional comments received after 8/20/92 will be incorporated or dispositioned (if incorporation is not appropriate) with the author.

Incorporation will be dependent upon the date a comment is received (the earlier received the higher the probability of incorporation), the severity of the comment (technical errors as contrasted to readability errors), and the extent of testing already conducted when the comment is received (IST must ensure uniformity in testing).

Comments Received on Test Procedures:
Page 5, Paragraph 1.1.1.1.2 - Sample frame; test data should be fire PDU.
Page 9, Paragraph 2 - PDU tests; time stamp field should be all zeros.
Page 13, Paragraph 2.3 - Parts field should be "omitted" or "don't care".
Page ?, Paragraph 3.1 - Terrain orientation comparison testing. Will add ships. All that is needed are PDUs from companies (unobtrusive testing).
Schedules for testing Aug. 12 - ready Aug. 15.

Page 20, Paragraph 4.2.1 - Location is consistent. Section 0.3 - Change wording; do not want to implement Section 3.2 Section 4.2.1 Why 675 BAMS? For one meter accuracy. Section 4.1.1.1 - Set time stamp; change wording. Section 4.2.1 - Routing; Right Isosceles Triangle. Section 4.3.1.2 - Test this feature. Section 4.3.1.5 Section 5.2.20.1 - Bounding volume is of fixed dimensions. Section 5.3(8/20/92).The rehearsal ground rules will be sent out in a week (9/23/92).

STATUS: OPEN. (9/23/92)

ACTION 51: Gamini Bulumulle briefed on steps to follow to gain access to the test network: Serial Line Internet Protocol (SLIP) or point to point protocol (PPP) must properly perform on the remote computers/simulators before anybody may gain access to the network. Please telephone IST in advance for a schedule appointment. Use this number for scheduling 407-658-5512 During the scheduled time dial into IST using the following telephone numbers: 1-800-226-5023; 1-800-226-5042 Remote users should get the following "login" prompt: Netblazer login: password: (enter issued password)

Separate Login names and Passwords will be assigned to each remote user. If SLIP or PPP installation is done properly then the remote login user should get the following message:
"Packet Mode Enable" which indicates the TCP connection with the IST network. Presently, the test network at IST contains only "Data logger" and "SAFOR" but other hardware and test features will be added to the network in the near future. Because UDP/IP broadcast mode will be used for testing purposes each node at the network will receive all of the broadcasted PDUs. Public domain (SUN) SLIP can be accessed by typing:
FTP WUARCHIVE.WUSTL.edu
Public domain (SUN) PPP can be accessed by typing:
next2.ist.ucf.edu; 132.170.190.2

Gamini requested the following information from all demo players:

IP address
Login name
Password (provided by Gamini)
SLIP/PPP

STATUS: CLOSED. (9/23/92)