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The Fundamentals Associated with Developing/Transitioning Advanced M&S Concepts of the Future

A State-of-the-Art Review

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Under the direction of DoD, future Modeling and Simulation (M&S) efforts will be required to comply with the High Level Architecture (HLA) set forth by the Defense Modeling and Simulation Agency (DMSO). This document provides the fundamental guidelines associated with developing/transitioning advanced M&S concepts of the future as required by DoD.

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1.0 INTRODUCTION

Prior to 1990, modeling & simulation (M&S) efforts within the Department of Defense (DoD) was fragmented and lacked coordination across all the Services. As a result, Congress directed DoD to establish a joint program office for simulation to coordinate policy, establish interoperability standards and protocols, promote simulation within the military, establish guidelines and objectives for coordination of simulation, wargaming, and training. This joint program office was established under the Office of the Secretary of Defense (OSD), and designated the Defense Modeling and Simulation Organization (DMSO).

The new direction has brought about significant advances in M&S in four areas:

- Architectures, standards, and protocols
- Representation of the environment, systems, and human behavior
- Fielding of M&S and associated infrastructure
- Outreach activities

This new direction in M&S forced a new idea originally called Advanced Distributed Simulation (ADS). This proved to be a major advance in real-time simulation ability, by being able to create large virtual worlds in which many subjects could interact. By electronically linking individual simulations, the creation of a virtual world revolutionizes planning, training, testing, analysis, and acquisition.

This document will discuss the DoD vision for M&S established in the early 1990's, and will identify the trends in ADS interoperability and architecture.

2.0 DoD VISION FOR M&S

As stated in the DoD M&S Master Plan (ref. 1) the Vision encompasses models and simulations ranging from high-fidelity engineering models to highly aggregated, campaign-level simulations involving joint forces. It includes all types of models and simulations containing a full range of M&S interaction between scope of the simulation, sponsoring component objectives and functional area requirements. Figure 1 illustrates the range of M&S contained by the DoD Vision. It notes there are many other perspectives of M&S including the level of resolution, degree of human participation, degree of physical realism, time-management method, time-step resolution, degree of distribution, and computational complexity.

The advanced M&S concepts may integrate a mix of constructive computer simulations, system simulators, as well as real system hardware. These simulation components (entities) may be distributed geographically and connected through a high-speed network and will allow users to train and analyze operational, or strategic levels of war through the use of synthetic environments representing potential opponents in any region of the world, with realistic interaction. Personnel may use the same synthetic environments for research, development, and test and evaluation activities as well as to support the acquisition decision making process. M&S will increasingly be used to

Additional M&S Dimensions

- Level of Resolution
- Degree of Human Participation
- Degree of Physical Realism
- Time Management Method
- Time Step Resolution
- Degree of Distribution
- Computational Complexity

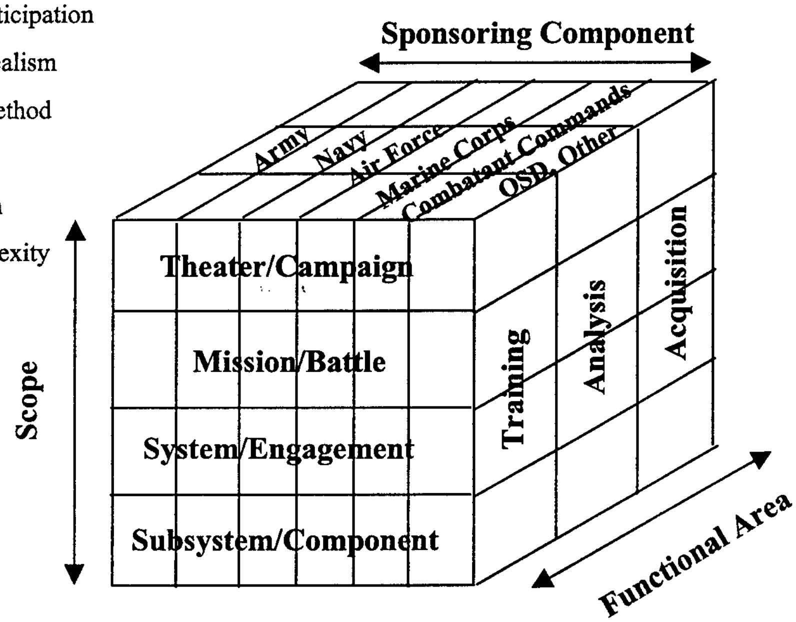

Figure 1. Range of M&S contained by the DoD M&S Vision (ref. 1)

reduce cost, improve efficiency and effectiveness in engineering development and system design, manufacturing, and logistical support functions. As discussed in reference 1, there are six activities required for transforming the Vision into reality as shown below in figure 2.

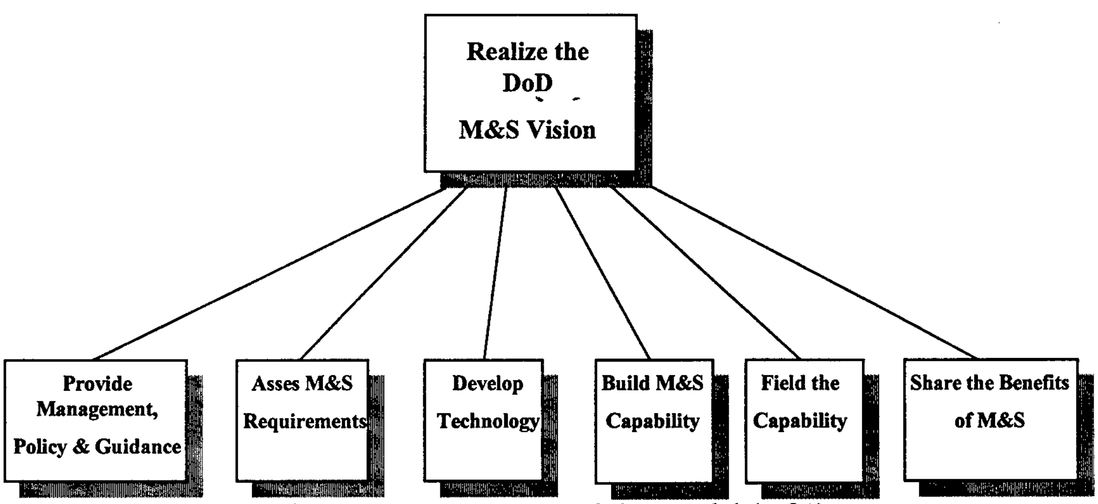

Figure 2. DoD M&S Activity Model (ref 1)

a. Provide Management, Policy & Guidance. Each DoD Component publishes appropriate directives, establishes organizations to support its M&S activities, and develops plans and budgets to satisfy the M&S needs of its Active and Reserve components as well as those of the United Combatant Commands and other DoD Components. The Under Secretary of Defense for Acquisition and Technology (USD(A&T)) may assign responsibility for development and maintenance of a specific common or general-use M&S capability to a DoD Component by formally designating the Component as an Executive Agent. The DoD Components may also further their M&S goals by organizing partnerships within their own organizations or with other DoD Components to address common interests. Each Component must make prudent investments to achieve DoD's M&S objectives.

b. Assess M&S Requirements. The needs of all DoD users must be identified and an assessment must be made to determine the potential and cost-effectiveness of M&S to satisfy the needs. The resulting M&S requirements must be prioritized for use in program planning, budgeting, and execution.

c. Develop Technology. It is necessary to continually monitor ongoing industry and government technology developments and assess the risk and cost-benefit of the technologies to support the requirements of the DoD Components for M&S. The technology shortfalls must be identified and priorities must be developed for DoD investments to exploit technology advances in a timely manner, accelerate technological development, fill technology gaps, and rapidly insert the acquired technology into M&S applications. The Director of Defense Research and Engineering's (DDR&E) Technology Area Plan and M&S Technology Area Review/Assessment are central facets of this activity.

d. Build M&S Capability. A technical framework must be developed to ensure appropriate interoperability across different simulations; reuse of simulation components; insertion of new technologies; and flexibility to respond to changing requirements. Then the DoD Components must employ the necessary technology to build the M&S representations (e.g., entities, applications and systems) and ensure they are populated with certified data. These representations must then be verified, validated, and integrated to provide a useful M&S capability.

e. Field the Capability. The DoD Components must plan the fielding of required M&S applications and systems. The required staffing, communications, data, and management infrastructure must be provided; the M&S software and/or systems must be delivered to the users; and the users must be properly trained in their use, including how to make accreditation and certification decisions. Users will then employ the M&S capabilities to improve readiness, support modernization, and support force structure and sustainment decisions. Configuration Management policies will ensure consistent, compatible M&S usage across the DoD Components.

f. Share the Benefits of M&S. The optimal use of M&S across DoD will not occur unless the positive (and negative) impacts and cost-effectiveness of M&S are documented and communicated. The DoD Components must educate potential user communities on the existing and expected benefits of M&S employment so that they make informed investment decisions. This education may include a wide variety of means, such as on-line information systems, seminars, live demonstrations, formal courses of instruction, etc. Where authorized and cost-effective, DoD must aggressively pursue the exchange of M&S-related requirements, concerns, ideas, and technology among the DoD Components, other Government Agencies, academia, industry, and allied nations.

3.0 DISTRIBUTED INTERACTIVE SIMULATION

In 1983 a program to establish a network of single trainer simulations into team trainers was created. This program called Simulation Networking (SIMNET) was sponsored by Advanced Research Projects Agency (ARPA) and launched a new technology known as ADS. SIMNET was successful in that it networked over 300 simulators with the technology that was to develop into Distributed Interactive Simulation (DIS).

DIS is based on a standard set of messages and rules called Protocol Data Units (PDU) which are used for sending and receiving information across a computer network. The most common message is the Entity State PDU which represents all of the state information about a simulated entity (i.e., tank, aircraft, rocket, human, etc.) that another simulator needs to know. An Entity State PDU contains data about an entity's position and velocity. By using position, velocity, acceleration, and rotational velocity data, a receiver is able to extrapolate, or dead reckon, a vehicles' position before the arrival of the next PDU, thereby reducing consumption of network bandwidth. Dead reckon means a simulator is able to recognize data within a PDU has not changed, from the previous, and therefore the Entity State is unchanged. Dead reckoning is a technique that reduces the frequency at which information must be transmitted via the underlying network, therefore DIS is able to significantly limit the amount of data an average simulator transmits. Dead reckoning permits very large DIS simulations to take place. Figure 3 illustrates the ADS and DIS architectures.

Basically in the ADS architecture, a centralized server performs the time-step tasks or change in data between all simulators and calculates the change in state information then sends it back out to each simulator. In DIS, there is no central server. DIS is a peer-to-peer architecture, in which all data is transmitted to all simulators where it can be rejected or accepted depending on what data the simulator needs. Eliminating a central server dramatically reduces time lag, called latency. This becomes very important when networking simulations and there is a requirement to represent realism or real-time, especially for training.

In 1994, reports on Advanced Distributed Simulation and Readiness have recommended that *architectural* efforts to combine *live*, *virtual*, and *constructive* simulation be broadened. In addition, other studies indicated the need for architectural activities to promote the interoperability and reuse of models and simulations to support other functional areas such as acquisition (ref. 1).

Simulations can be *live*, *virtual*, or *constructive* data sources

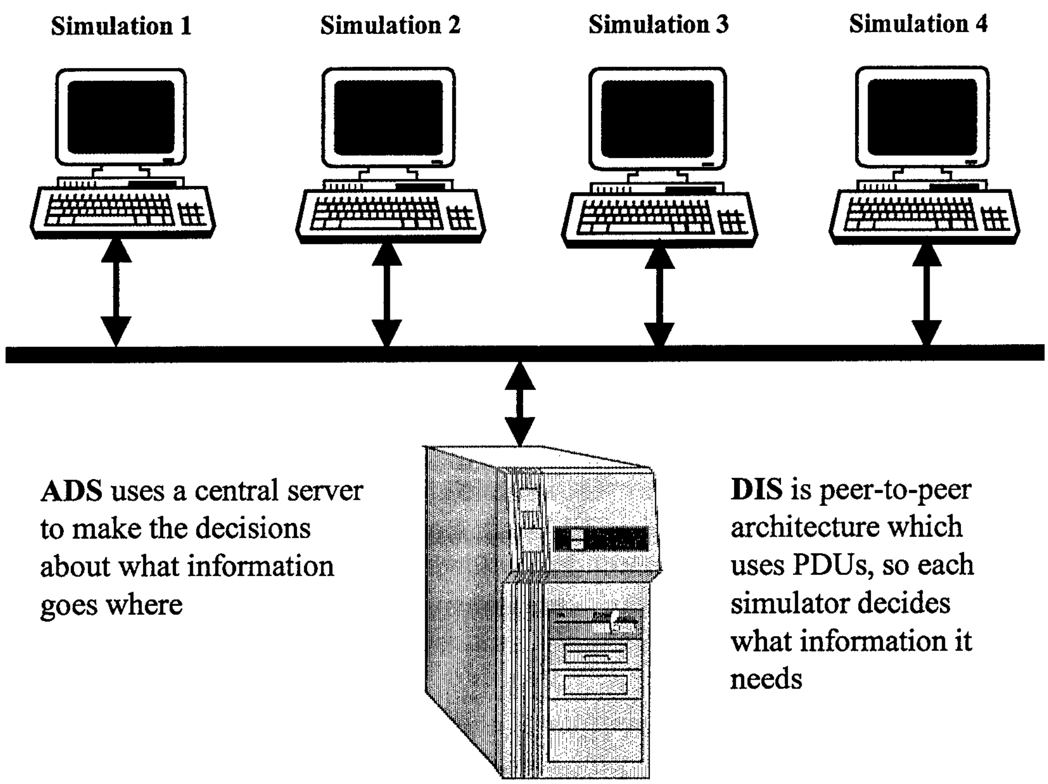

Figure 3. ADS and DIS Architectures

It was noted that interoperability and reuse were limited because DoD lacked a common technical framework for simulation architecture. As a result, developed a consensus that DoD must establish such a framework to facilitate the interoperability of all types of models and simulations among themselves and with C4I Systems, as well as to facilitate the reuse of M&S components. This soon turned into a program established by ARPA to develop DIS standards (IEEE Standard 1278).

3.1 DIS AREAS OF STANDARDIZATION

The DIS standards establish a common data exchange environment, also known as a common messaging environment, using PDUs, that supports the interoperability of heterogeneous, geographically distributed live (operational platforms and test and evaluation systems), virtual (human-in-the-loop simulators) and constructive entities (wargames and other automated simulations). As discussed in reference 2, the following DIS areas of standardization include interface definition, communication, security, management, representation of the environment, field instrumentation, and performance measurement.

3.1.1 Interface Definition

The definitions of how information must flow between simulations in order to be interoperable include:

- Identification of data items
- A common representation of these data items
- The assembly of these data items into formatted messages, called PDUs
- The circumstances (including time) under which these PDUs are transmitted
- The processing that must be done on receipt of PDUs
- Key algorithms (e.g. dead reckoning) that must be implemented by all participants

These definitions have been documented in the IEEE Standard 1278. This initial version defines the PDUs needed to support the appearance and movement of entities, firing of weapons, detonation of ordnance, collision detection, and logistical resupply of units.

Subsequent versions of this document are available (DIS 2.X series) to support current developments. These new versions correct shortcomings and support new capabilities:

- Simulated voice radio and tactical data links
- Simulation management
- Emission representation in support of electronic warfare
- Terrain description
- Environmental effects

3.1.2 Communication Architecture

DIS PDUs are independent of network media and network protocols being used to transmit them. PDUs define the information that flows between simulations; and communications architecture standards ensure that the underlying media, types of service, and protocols are common and meet key performance requirements. The areas associated with Communication standards are:

- Definition of addressing (e.g. point-to-point, one-to-many) capabilities
- Definition of reliability (e.g. error free, best effort) requirements
- Choice of communication profile for the network and transport layers (as defined by the International Standards Organization/Open System Interconnection (ISO/OSI) technical reference model)

- Guidance in determining bandwidth requirements based on estimated traffic for exercises of different sizes
- Definition of key constraints (e.g. maximum PDU size)
- Definition of key performance capabilities (e.g. latency)

Unlike the definition of PDUs, which can be arbitrarily defined to suit specific DIS needs, communications standards are heavily impacted by what the communications industry offers or is expected to offer. Many fundamental communications needs of DIS (e.g. multicast addressing) are not normal of traditional communications developments, which are based on the telephone model of point-to-point connection. This has made the selection of available services difficult and has forced some compromises in DIS operations.

3.1.3 Security

Most DIS-based applications will require protection of the information flowing between simulations. The applications, which require protection, will range from individual companies wishing to keep proprietary data away from competitors to rehearsal of planned military operations, the most sensitive application foreseen. DIS standards development in the area of security consists of:

- Establishment of a DIS security policy
- Publication of a DIS security guidance document
- Publication of security accreditation guidelines
- Establishment of security services performance requirements

It should be noted that none of the efforts mentioned above would in any way determine what data needs protection or how well the data needs to be protected. These issues are the responsibility of the authority in charge of each DIS simulation application and will vary from application to application. Instead, these efforts are intended to assist accreditors, engineers, and managers in determining what protection measures are available and how they may be most effectively used. These efforts will also clarify the needs of DIS data protection mechanisms to help the developers of such mechanisms (e.g. encryption/decryption devices, secure operating systems, and key distribution methods). Another purpose a standardized accreditation process for DIS-based applications that is widely understood and easily used.

3.1.4 Management

The planning, setup, execution, and monitoring of a large, multi-site exercise is a complex process that may ultimately prove to be a greater challenge than managing the network traffic itself. Significant amounts of person-to-person communication, via video conferencing and other techniques, will be required in advance of an exercise. This will insure that the exercise objectives are understood and agreed to by all parties involved, and that the required resources, in terms of simulations, personnel, and communications bandwidth, are available at the appropriate times.

Configuration management will play an important role, particularly where many heterogeneous simulations are involved. Each simulation has its own set of adjustable parameters, each of which must be recorded if there is to be any chance of replicating the exercise. Where interfaces to wargames are included, they can easily represent thousands of parameters to be recorded.

Other areas in DIS management standardization include exercise management, network management, and security management.

3.1.5 Environment

The synthetic environments simulated in DIS need to present a full-bodied, integrated representation of land, air, and sea. A full-bodied, integrated representation includes other windows of the electromagnetic spectrum such as infrared and ultraviolet. Two considerations affect this issue: fidelity of environmental representation (for validation of the simulation exercise consistent with the exercise purpose), and correlation of representations from system-to-system to ensure the fair fight. The concept of a fair fight also includes:

- Adequate inclusion of entity capability to support individual actions (e.g. controls and displays, subsystems, modes of operation, physical limitations)
- Accurate representation of actions by all affected participants

DIS efforts for achieving commonality of environmental representation among heterogeneous simulators, simulations, and range systems are focused on an infrastructure to:

- Identify common sources for environmental data
- Create standards for the representation of that data
- Create repository databases for the collection and storage of the common data
- Distribute that data to local systems in an exercise
- Aid DIS users in identifying exercise requirements and then decomposing them into participant capabilities and fidelity requirements
- Catalog DIS qualified simulation assets from which DIS users can select an appropriate subset to meet exercise goals, including exercise validation

3.1.6 Field Instrumentation

Instrumented platforms have unique requirements and historically have not been addressed by DIS standards. To address these issues the DIS community established a separate effort to develop standards that will allow instrumented platforms to interact with virtual and constructive simulation components in a meaningful way. Some of the areas addressed include:

- More compact representation of data necessitated by the lower bandwidth of Radio Frequency (RF) communications used by the instrumented ranges
- The special needs of mobile instrumented platforms
- The fusion of simulated information with that provided by the sensors of the instrumented platforms
- Intelligent translation of information flowing from the instrumented range to the virtual world
- The special safety considerations of live range interactions
- Interfaces which allow exchange of tactical data link information between live, virtual and constructive simulations
- Special protocols to handle live range activities

3.1.7 Performance Measurement

In order for a DIS-based application to have value that can be stated objectively, a great deal of effort must be put into defining, recording, and analyzing data that represents the behavior of the participants. Such measures of performance are essential to the Verification, Validation, and Accreditation (VV&A) needed to determine whether a planned DIS-based application is appropriate to its intended purpose. Eventually such performance measurement will also be the basis of efforts to determine the effectiveness of behaviors seen in DIS-based applications.

Standards development efforts in the area of performance measurement center on:

- Establishing a standard set of performance measures
- Developing mechanisms to gather appropriate data
- Identifying and extracting meaningful parameters from that data
- Presenting such parameters in a manner that is easy to understand and absorb
- Collecting data from remote sites at a central location

4.0 HIGH LEVEL ARCHITECTURE

High Level Architecture (HLA) is the next generation of modeling and simulation software that will support a wider range of applications with more functionality. As previously mentioned, DoD has directed an effort to establish a common technical framework to facilitate both the interoperability between the wide spectrum of modeling and simulation applications and the reuse of the modeling and simulation components. This common technical framework, HLA, is shown in figure 4 and is considered the highest priority effort within the DoD modeling and simulation community.

4.1 GENERAL PRINCIPLES

HLA uses a set of rules to govern how simulations interoperate with each other. These simulations are referred as federates, which communicate by a data distribution mechanism called the Runtime Infrastructure (RTI) and uses an Object Model Template (OMT) which describes the format of the data. This is analogous to the PDU and Entity State formats used in DIS. However, HLA does not specify what constitutes an object (objects are the physical things that are going to be simulated, such as tanks and missiles), nor the rules of how objects interact. This is the key difference between DIS and HLA.

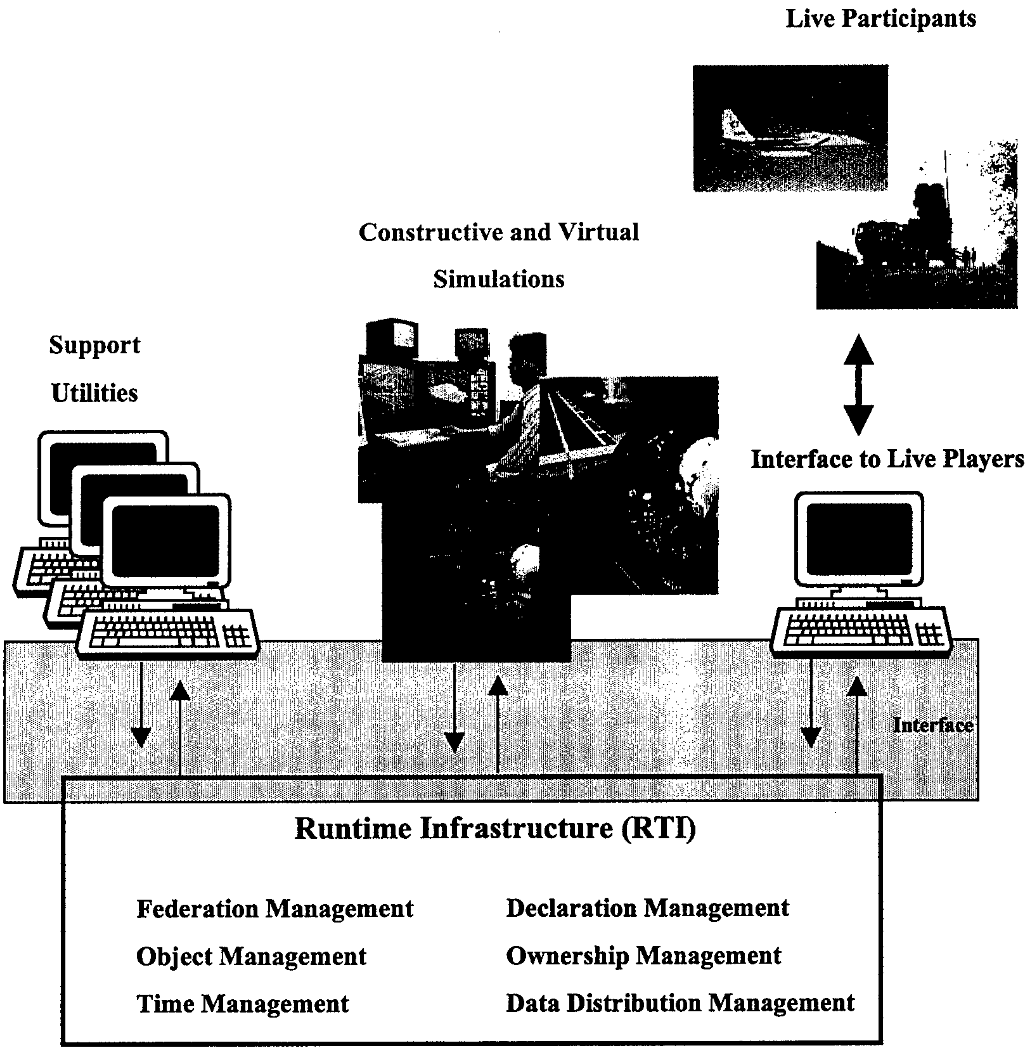

Figure 4. High Level Architecture (HLA)

In DIS it would not be possible to interact applications of high-fidelity engineering models which run much slower than real time and lower-fidelity models which may run at real-time or faster with very high accuracy. The HLA RTI allows different types of systems of different levels of fidelity and scope to interact.

However, this level of flexibility in HLA causes an inherent weakness – unless all the HLA simulators in an exercise agree on a single Federate Object Model (FOM) they will not be able to interoperate even though they are HLA compliant. The FOM describes the objects and interactions involved in the federation execution (ref. 3).

Unlike DIS where all simulations receive every piece of data broadcast, HLA provides the federates a more flexible simulation framework with the ability to specify:

- What information they will be producing
- What information they would like to receive
- The data's transportation service, e.g. reliable, best effort
- Whether or not the federation's timing mechanism is synchronous or asynchronous

These points make it possible to have more simulations on a network at one time because the amount of data being sent is reduced. The simulation software is also simplified because it does not need to process extraneous information.

4.2 RULES/RATIONAL

The overall objective of a common technical framework, is to support interoperability and reuse. Therefore it is essential to establish certain rules by which the HLA must comply. There are a total of ten HLA rules; five for federations and five for federates (ref. 4).

4.2.1 Federation Rules

A federation is a named set of interacting federates, a common federation object model and supporting Runtime Infrastructure, that are used as a whole to achieve a specific objective. Below are the five rules and rational that apply to HLA federations.

1. <u>Federations shall have an HLA Federation Object Model (FOM), documented in accordance with the HLA Object Model Template (OMT).</u> The FOM is the fundamental element in defining a federation. It shall document the agreement among federates within the federation data to be exchanged at runtime and the conditions of the data exchange. The requirement that FOMs be documented in accordance the HLA OMT is to support reuse of a federation by new users.

2. <u>In a federation, all simulation-associated object instance representation shall be in the federates, not in the runtime infrastructure (RTI).</u> The main purpose in the development of HLA was to separate simulation specific functionality (updating values) from general purpose supporting infrastructure (interaction of object instances across the federation). Representation of simulated object instances (e.g. ownership of instance attributes, where

"ownership" is defined as having the responsibility to update values) shall take place in the simulations (federates). The RTI provides functionality similar to a DIS operating system by supporting interaction of object instances. However, the RTI may own instance attributes associated with the supporting services, such as declaration management, within the federation management object model. But, these data are just used by the RTI, not changed.

3. During a federation execution, all exchange of FOM data among federates shall occur via the RTI. The RTI is setup such that it provides services by which data exchanged among federates in a federation (intercommunication) is accomplished. The HLA shall specify a set of interfaces to these RTI services in order to support exchange of instance attribute values and interactions in accordance with the FOM for that federation. Based on the FOM, it will be the responsibility of the federate to identify to the RTI what information they will provide and require (which data, reliability of transport, event ordering, etc.), along with instance attribute and interaction data corresponding to the changing state of object instances in the federate. It will be the responsibility of the RTI services to provide the coordination, synchronization, and data exchange among the federates to permit a coherent execution of the federation.

4. During a federation execution, federates shall interact with the RTI in accordance with the HLA interface specification. The interface specification defines how simulations interact with the infrastructure. Federates will use these standard interfaces to interact with the RTI for accessing RTI services. The interface specification has no ownership or say so about specific federate data to be exchanged over the interface. Data exchange requirements between federates shall be defined in the FOM. The separation of the interfaces from the requirements for federate data exchange allows for the reuse of a common interface specification across the broad spectrum of simulation applications, with specific application needs tailored through the FOM mechanism.

5. During a federation execution, an instance attribute shall be owned by at most one federate at any time. In HLA different federates are allowed to own different attributes of the same object instance. For example, a simulation of an aircraft might own the location of the airborne sensor while a sensor system model might own other instance attributes of the sensor. By allowing at most one federate ownership of an object instance attribute at any time will ensure data coherency across the federation. HLA will provide a mechanism to transfer ownership, dynamically during execution, from one federate to another. By defining ownership at the instance attribute level and providing the tools to hand off ownership during execution, the HLA provides a flexible toolset for using various combinations of simulations to meet user needs.

4.2.2 Federate Rules

A federate is a member of a HLA federation. A federate may include federate managers, data collectors, live entity surrogate simulations, model simulations or passive viewers. Below are the five rules and rational that apply to HLA federates.

1. Federates shall have an HLA Simulation Object Model (SOM), documented in accordance with the HLA OMT. Federates are defined as simulations or other applications such as simulation managers, data collectors, live entity interfaces, and passive viewers participating in a federation. The HLA requires each federate to have a simulation object model (SOM) which will include those object classes, class attributes, and interaction classes of the federate that can be made public in a federation.
It will not be the responsibility of HLA to prescribe which data are included in the SOM, this will be done by the simulation developer. HLA will require that SOMs be documented in a prescribed format called the HLA OMT.

2. Federates shall be able to update and/or reflect any attributes and send and/or receive interactions, as specified in their SOMs. The HLA allows federates to make object representations and interactions developed for internal use available as part of federation executions for external use with objects represented in other federates. These capabilities for external interaction shall be documented in the SOM for the federate. These federate capabilities shall include the obligation to export updated values of instance attributes that are calculated internally in the federate and the obligation to be able to exercise interactions represented externally (i.e., by other federates in a federation). By designing federates from the outset with the ability to present internal objects/attributes/interactions as public, the mechanisms for reuse of the simulation will be in place from the start.

3. Federates shall be able to transfer and/or accept ownership of attributes dynamically during a federation execution, as specified in their SOMs. HLA allows for different federates to own different attributes of the same object instance (e.g., a simulation of an aircraft might own the location of the airborne sensor while a sensor system model might own other instance attributes of the sensor). With this capability, it shall be possible to allow a simulation designed for one purpose to be coupled with one designed for another purpose to meet a new requirement. By building in the capability to transfer and accept ownership of instance attributes, simulations designed in accordance with the HLA provide the basic structural tools to become federates in the widest possible range of future federations. The instance attributes of a federate that can be either owned of reflected, and that can be dynamically transferred during execution, are documented in the SOM for that federate.

4. Federates shall be able to vary the conditions (e.g., thresholds) under which they provide updates of attributes, as specified in their SOMs. HLA permits federates to own (i.e., produce updated values for) attributes of object instances represented in the simulation and then make those values available to other federates through the RTI. Different federations may specify different conditions under which instance attributes will be updated (at some specified rate, when the amount of change in value exceeds a specified threshold such as altitude changes of more than 1000 feet, etc.). Widely usable simulations will be able to adjust the conditions under which they export their public instance attributes to support the requirements of different federations. The conditions applicable to the update of specific instance attributes of a federate shall be documented in the SOM for that federate.

5. Federates shall be able to manage local time in a way that will allow them to coordinate data exchange with other members of a federation. The HLA time-management structure is intended to support interoperability among federates using different internal time-management mechanisms. The HLA shall support these capabilities provided that federates adhere to certain requirements necessary to realize each service. To achieve these goals the approach to time management is being developed to provide time-management interoperability among disparate federates. Different categories of simulations are special cases in this unified structure, and typically use only a subset of the RTI's full capability. Federates need not explicitly indicate to the RTI the time-flow mechanism (time stepped, event driven, independent time advance) being used within the federate, but shall utilize the RTI services (including time management) that are appropriate for coordination of data exchange with other federates.

4.3 RUNTIME INFRASTRUCTURE

The RTI is the general purpose distributed operating system software, which provides the common interface services during the runtime of an HLA federation. Its primary function is that of a data distribution mechanism. Federates send information through the RTI, which distributes the information to the appropriate parties. Each RTI component (linked into each federate) must perform synchronization operations with the other RTI components to allow a federation to progress in time, handle ownership management, join federations, and update Management Object Model (MOM) state. The RTI does not maintain information about the state of the federation. Nor does it handle any semantics associated with the interaction between the federates, such as what coordinate system to use, what happens during a collision, or how to dead-reckon remote vehicles. Also, the RTI does not specify the exact byte layout of data sent across the network.

The RTI provides a common set of services to the federates. They can be divided into six functional interfaces as shown in figure 4. The HLA is not the RTI; the HLA says there will be an RTI that meets HLA requirements but it doesn't specify a particular software implementation. RTI software, and other HLA related items, are available now and can be ordered from the DMSO homepage (http://hla.dmso.mil) under topic "HLA Software Distribution Center". Currently six ports for RTI are available and each port includes:

- RTI software
- Installation guide
- User documentation
- Test federate
- Sample application

Currently, RTI version 1.0 is available and version 1.3 is planned for release by the second quarter of calendar year 98. RTI version 2.0 commercial procurement is underway and scheduled to be released late 98 (TBD).

4.4 INTERFACE SPECIFICATION

The rational to develop an Interface Specification for HLA was to establish *interoperability* and utilize the *reuse* among simulations within a federation, and across functional M&S communities. The Interface Specification (ref. 5) defines the interface services between the runtime infrastructure and the federates subject to the HLA. As previously mentioned in section 4.3, the interface between federates and RTI are divided into six service groups. Each service group specification includes:

- Name and Descriptive Text
- Supplied Arguments
- Returned Arguments
- Pre-conditions
- Post-conditions
- Exceptions
- Related Services

The six HLA RTI service groups each have services performed under that group as described below (ref. 5).

1. Federation Management: Handles the creation, dynamic control, modification, and destruction of a federation execution. This group has includes 20 services listed below:

- Create Federation Execution
- Destroy Federation Execution
- Join Federation Execution
- Resign Federation Execution
- Register Federation Execution
- Confirm Synchronization Point Registration
- Announce Synchronization Point
- Synchronization Point Achieved
- Federation Synchronized
- Request Federation Save
- Initiate Federate Save
- Federate Save Begun
- Federate Save Complete
- Federation Saved
- Request Federation Restore
- Confirm Federation Restoration Request
- Federation Restore Begun
- Initiate Federate Restore
- Federate Restore Complete
- Federation Restored

2. Declaration Management: Enables federates to declare to the RTI their desire to generate (publish) and receive (subscribe/reflect) object state and interaction information. Federates can subscribe to only the objects they want (or have the capability) to receive, e.g. tanks might need only data pertaining to ground movement, or airplanes might need only data pertaining to flight activities. This group contains 12 services listed below:

- Publish Object Class
- Unpublish Object Class
- Publish Interaction Class
- Unpublish Interation Class
- Subscribe Object Class Attributes
- Unsubscribe Object Class
- Subscribe Interaction Class
- Unsubscribe Interaction Class
- Start Registration for Object Class
- Stop Registration for Object Class
- Turn Interactions On
- Turn Interaction Off

3. Object Management: Support life cycle activities of objects and interactions. Enables the creation, modification, and deletion of objects, their attributes and the interactions. These services comprise most of the network traffic during runtime. This group contains 17 services listed below:

- Register Object Instance
- Discover Object Instance
- Update Attribute Values
- Reflect Attribute Values
- Send Interaction
- Receive Interaction
- Delete Object Instance
- Remove Object Instance
- Local Delete Object Instance
- Change Attribute Transportation Type
- Change Interaction Transportation Type
- Attributes in Scope
- Attributes Out of Scope
- Request Attribute Value Update
- Provide Attribute Value Update
- Turn Updates On for Object Instance
- Turn Updates Off for Object Instance

4. Ownership Management: Allows federates to transfer ownership of object attributes to other participants in the simulation. Federates transfer ownership based on federation execution design plans. The RTI makes the decision for transactions so that ownership is

held by at most one federate at any time. Ownership acquisition attempts can be both *invasive* or based on *opportunity*. This group has 16 services listed below:

- Unconditional Attribute Ownership Divestiture
- Negotiated Attribute Ownership Divestiture
- Request Attribute Ownership Assumption
- Attribute Ownership Divestiture Notification
- Attribute Ownership Acquisition Notification
- Attribute Ownership Acquisition
- Attribute Ownership Acquisition if Available
- Attribute Ownership Unavailable
- Request Attribute Ownership Release
- Attribute Ownership Release Response
- Cancel Negotiated Attribute Ownership Divestiture
- Cancel Attribute Ownership Acquisition
- Confirm Attribute Ownership Acquisition Cancellation
- Query Attribute Ownership
- Inform Attribute Ownership
- Is Attribute Owned by Federate

5. Time Management: Provides useful services for setting, synchronizing, and modifying simulation clocks. Time Management services are tightly coupled with the Object Management services so that state updates and interactions are distributed in a timely and ordered fashion. This group has 23 services listed below:

- Enable Time Regulation
- Time Regulation Enabled
- Disable Time Regulation
- Enable Time Constrained
- Time Constrained Enabled
- Disable Time Constrained
- Time Advance Request
- Time Advance Request Available
- Next Event Request
- Next Event Request Available
- Flush Queue Request
- Time Advance Grant
- Enable Asynchronous Delivery
- Disable Asynchronous Delivery
- Query Lower Bound Time Stamp (LBTS)
- Query Minimum Next Event Time
- Modify Lookahead
- Query Lookahead
- Retract

- Request Retraction
- Change Attribute Order Type
- Change Interaction Order Type

6. Data Distribution Management: Federates can provide conditions governing when to start or stop transmitting and receiving certain pieces of data. The RTI routes data from producers to consumers based on Data Distribution Management declarations. During the Federation design, *routing spaces* are created for use during runtime. These are specified at federation creation time in the Federation Execution Details (FED) file. There are 13 service associated with this group:

- Create Region
- Modify Region
- Delete Region
- Register Object Instance with Region
- Associate Region for Updates
- Unassociate Region for Updates
- Subscribe Object Class Attributes with Region
- Unsubscribe Object Class with Region
- Subscribe Interaction Class with Region
- Unsubscribe Interaction Class with Region
- Send Interaction with Region
- Request Attribute Value Update with Region
- Change Thresholds

In addition to the six service groups, the Interface Specification also includes 29 support services, Management Object Model, Federation Execution Data, Application Programmers Interfaces (APIs), and Harel state charts (ref. 6).

4.5 OBJECT MODEL TEMPLATE

The OMT provides a standard format for describing a simulation in terms of its objects and the relationship between objects. Objects are the physical things, real-world entities that are simulated, and the relationship is the event(s) that occur in simulations, between objects.

There are three basic characteristics used by HLA to view an Object - *identity*, *state*, and *behavior*. Features that distinguish objects from one another, such as a name, are described as an identity. The static and dynamic properties associated with an object at any time are regarded as the state. Behavior is described as how an object acts and reacts with respect to changes in state (ref. 6).

The relationship between objects is specified through - *attributes*, *association*, and *interaction*. Parameters, such as state variables of an object that can be accessible to other objects are called attributes. One object can be part of another object by conceptual connection called association. Interaction is defined as the influence of one object's state on the state of another object, such as detonations and collisions (ref. 6).

HLA provides a template to characterize object models (OMT). The rational to develop an OMT is again based on interoperability and reuse of simulations and a common framework. Within the template object models describe:

- Those objects chosen to represent real-world within a simulation or federation
- Attributes, associations, and interactions
- Level of fidelity by which these objects represent the real-world, to include spatial and temporal resolution
- Models and algorithms used to represent the objects

The OMT also consists of a Federation Object Model (FOM) and Simulation Object Model (SOM). FOMs are used to describe all shared information essential to a particular federation. A FOM is an identification of the essential classes of objects, object attributes, and object interactions that are supported by a HLA federation. SOMs are used to describe objects, attributes and interactions within a simulation, which can be used externally in a federation. A SOM is a specification of the intrinsic capabilities that an individual simulation publicly offers to federations. The standard format in which SOMs are expressed provides a means for federation developers to determine the suitability of simulation systems to assume specific roles within a federation.

5.0 DIS-TO-HLA CONVERSION

Under the direction from DoD that all models and simulations of the future must comply with the HLA, the question is what to do with the legacy models currently being used. Particularly, how do we handle the transition of existing Advanced Distributed Simulations to the HLA? DMSO is supporting several experimental applications in 1996 to test and refine the HLA concept. Reference 3 describes four techniques for making the

Table 1. Benefits of Four Techniques for Transitioning DIS to HLA (ref. 3)

	Translator	Wrapper	Native	PIU
Forward Compatibility	X	X	X	X
Backward Compatibility	X			X
Ease of use	X			X
Low Latency		X	X	X
Scalability		X	X	X
Takes full advantage of HLA			X	X

DIS to HLA translation. These four techniques are called - translator, wrapper, native, and protocol interface unit (PIU). Some are simpler and more cost-effective than others, and each has advantages and disadvantages. Table 1 lists the benefits of the four techniques.

From the table, Forward Compatibility describes the technique's ability to be upgraded to newer versions of HLA. Backward Compatibility describes the technique's ability to switch between HLA and DIS. Ease of Use means the simulation requires only limited modifications to existing software. Low Latency means the technique does not cause a delay between sender and receiver. The Scalability describes the technique's ability to interface with a large number of simulations. As discussed in reference 3, these four techniques are presented in detail below:

Translator: This technique requires a separate application or hardware device to manage communications between applications that use different protocols. Often another computer is placed on the network to translate network traffic between the different protocols. This technique requires no software modifications to the simulator, but the disadvantage is the simulator's latency increases roughly by a factor of ten. This technique does allow limited forward and backward compatibility, but limits the scalability and flexibility of the simulator. Another disadvantage when using this technique, the simulator cannot take advantage of future HLA features.

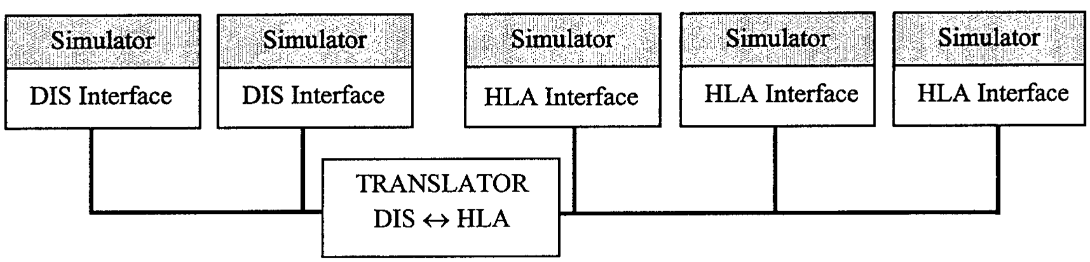

Figure 6. The Translator Technique (ref. 3)

Wrapper: This technique links additional code to a DIS application to provide interoperability with HLA applications. Software is added underneath the simulation's DIS interface to; (a) translate the data from the old DIS protocol to the new HLA protocol just before it is sent and (b) to translate the data from HLA to DIS just after it is received. This technique does not require additional hardware and all changes are made via limited modification to the simulator's software. Forward and backward compatibility requires software changes, and like the translator technique, the wrapper does not allow the simulator to take advantage of HLA specific features.

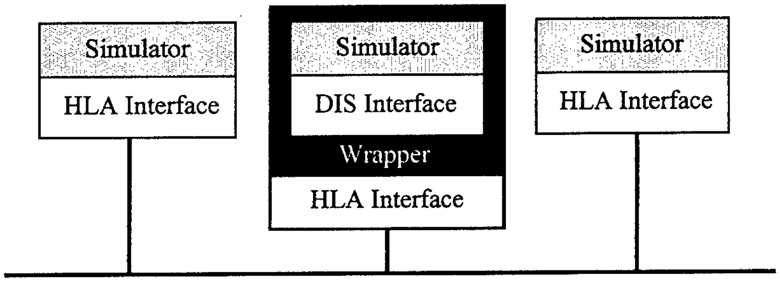

Figure 7. The Wrapper Technique (ref. 3)

Native: This technique requires the simulation software to contain all necessary interfaces to the network. A native HLA simulator can take full advantage of all HLA features. However, these advantages come at the expense of huge software modifications at the initial transition and then additional modifications for any future protocol changes. Also, there is no backward compatibility.

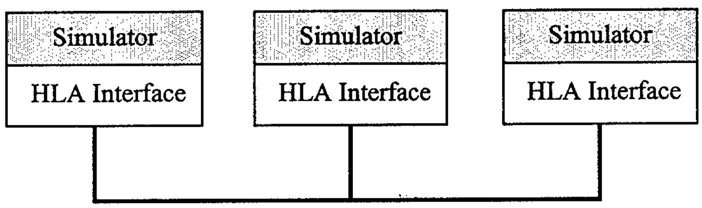

Figure 8. The Native Technique (ref. 3)

Protocol Interface Unit: This technique supports all features of both protocols, and allows switching among different FOMs within HLA. A Protocol Interface Unit (PIU) is a software system used to interface the simulation with the network. This approach may be the best technique to update a DIS simulator to HLA. It provides an easy upgrade path to HLA, while maintaining backward compatibility with DIS. A PIU requires only minimal modifications to the simulation software and provides the most flexibility when designing a new simulation. The disadvantage of using a PIU is that they can be complex and expensive to write and maintain. MÄK Technologies has developed a PIU called VR-Link™, which has one application programmer's interface (API - a library of function calls which allows a federate to interact with the RTI) which supports all the features in both protocols, DIS and HLA.

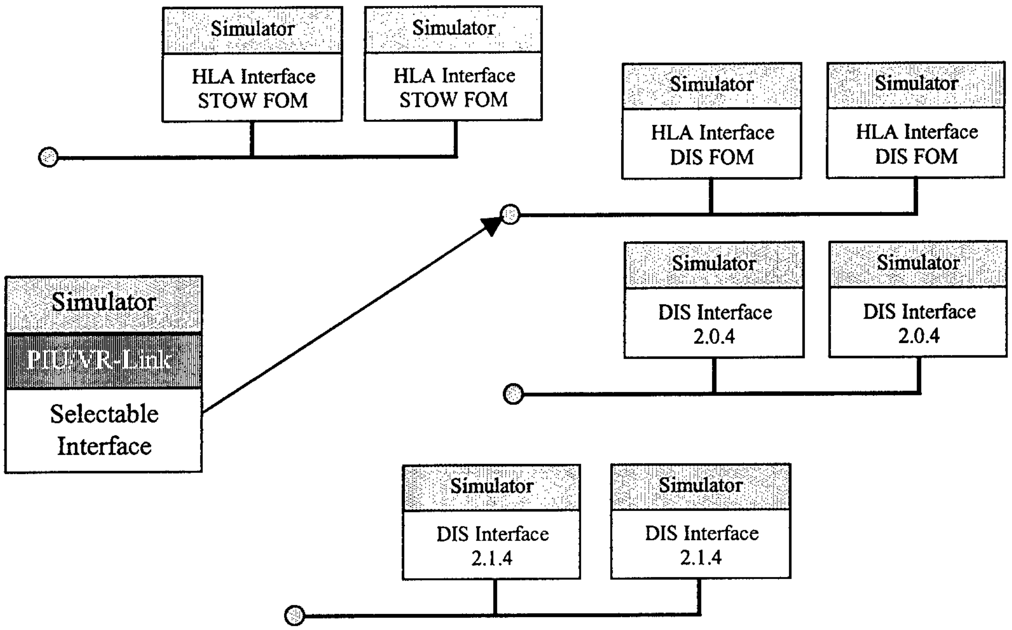

Figure 9. The Protocol Interface Unit Technique (ref. 3)

6.0 CONCLUSION

Under the direction of DoD, future M&S efforts will be required to comply with architecture called HLA to ensure interoperability and reuse. DoD policy has stated that on the first day of FY99 no funds will be available for developing/modifying non-HLA-compliant simulations. On the first day of FY01 non-HLA-compliant simulations will be retired. The new direction has brought about significant advances in M&S in four areas:

- Architectures, standards, and protocols
- Representation of the environment, systems, and human behavior
- Fielding of M&S and associated infrastructure
- Outreach activities

Given a shrinking force structure, limited resources, more demanding operation requirements, and more technical capability, the ADS concepts will offer a cost effective and affordable solution for training, performance assessment, test and evaluation, and analysis. As DIS moves into the direction of HLA existing models will be required to make the transition. This document has provided the fundamentals associated with developing/transitioning advanced M&S concepts of the future as required by DoD.

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