VALIDATION OF HARDWARE-IN-THE-LOOP (HWIL) AND DISTRIBUTED SIMULATION SYSTEMS

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I. INTRODUCTION

THESIS: The need for explicit verification, validation, and accreditation (VV&A) of hardware-in-the-loop models and simulations (M&S), distributed simulations, and their simulation components, particularly within the Department of Defense (DoD) environment, is clear. What processes, techniques, and tools, beyond those that are normally available for VV&A are necessary for support of this significant class of simulation assets is not entirely clear.

Environmental Context: Resource constraints, range and treaty limitations, environmental impacts of physical testing and scheduling requirements come together to force decision makers to rely less on expensive field and operational testing, and more on the results of simulation-based systems analyses which rely on complex, HWIL and distributed simulation systems. This is true in all phases of the weapon system life cycle.

In response, many new M&S hardware-in-the-loop (HWIL) and distributed simulation tools are being developed to support analysis, research and development programs, test and evaluation, and training. Some of these simulation tools will employ virtual environments to support man-in-the-loop (MIL) operations, distributed architectures, massively parallel processing, high performance computing, or other new technologies.

While these new models and simulations may offer improved capabilities for analysis, training, or test and evaluation, they will require substantial investment for their development, operations and maintenance. The expense of these assets and the importance of the decisions they influence, require that their capabilities and limitations be clearly understood and firmly established through formal VV&A processes and methods.

The Missile Defense Agency's '04 Testbed is a good example. Its investment costs are significant, but its contributions to ballistic missile defense systems (BMDS) engineering, analysis and test and evaluation are expected to be enormous. It will have an impact in ballistic missile system design and architectures, military tactics, training, and operations. The MDA Testbed is expected to influence many important decisions in the acquisition and support of a BMDS.

M&S VV&A Operational Context: The essence of V&V is to establish the degree to which decision-makers may have confidence in the results of studies and analyses conducted using the pertinent M&S tools. The scope of evidence that is applicable to that determination includes M&S development activities and M&S documentation; the configuration management (CM) process and supporting documentation; and V&V activities and the formal documentation of the results obtained from their execution. Much of the V&V process consists of generating, organizing, and reporting in an auditable form the evidence that may be developed or originates in the system development, test, and configuration management activities. Each of these related activities assist in establishing the foundation for user acceptance.

The special concern of this paper is to consider these special qualities of HWIL and distributed simulation assets, to analyze the peculiar requirements for VV&A

processes, practices, and tools, and to identify both the problems and opportunities of dealing with VV&A of these special systems.

HWIL and Distributed Simulation System State of Practice: The V&V strategies and methodologies presented herein have been successfully used by a number of organizations. The VV&A state-of-practice for HWIL and distributed simulation is detailed through the actual experiences of representative M&S development organizations from the Army, Navy, and Air Force. Policy is addressed, but, our focus is on relating the hard-lessons learned from practitioners in the field that have been grappling with developing HWIL and distributed simulations while implementing M&S VV&A policy guidance and staying within cost and schedule constraints. All, while satisfying the information needs of senior decision makers within the DoD and their component services and agencies.

1.1 SCOPE

This paper addresses the systematic verification and validation of HWIL, software-in-the-loop (SWIL), and distributed simulations, which often-incorporate complex, all-digital M&S, linked test beds, and associated test resources. The definitions of key M&S VV&A terms are provided and an assessment of the current DoD state-of-practice is discussed. Key policies and practices are reviewed. A few critical concepts are introduced which we believe are essential for establishing tailored, sufficient VV&A Plans for HWIL and distributed simulations, which can support decision makers and Accreditation Authorities in managing risks inherent in the use of simulations to solve their day-to-day problems. These notions are considered valuable not only for their utility to HWIL and distributed simulations, but for their potential application in other related M&S VV&A contexts as well.

The process by which a VV&A plan for HWIL and distributed simulations can be methodically developed will be delineated, and the typical results of such a process in terms of the program of assessment activities, and associated schedule, resources and products will also indicated. The results of employing the recommended planning process will be described.

Issue identification has been accomplished by considering the experiences of key HWIL facilities within the Army, Navy, and Air Force. This not only provides authentication for the concepts presented herein, but also presents useful case histories relating to VV&A of HWIL facilities as well as VV&A of particular HWIL or distributed simulations, or system assessments supported by these facilities. We will look at three HWIL facilities that have distinctive emphases (product areas): an Army facility which is focused mainly on missile systems, a Navy facility which deals primarily with surface and underwater operations, and an Air Force facility that has an electronic warfare (EW) emphasis.

Paper's Objective: Issues characteristic of V&V of HWIL and distributed simulations, and simulation frameworks will be identified and ameliorative strategies will be proposed.

Finally, potential research topics and technologies to advance the state-of-the-art for validation of HWIL and distributed simulations will be addressed.

1.2 KEY REFERENCES AND RESOURCES

In recent years there has been significant activity in the area of V&V and testing of M&S within the DoD. As a result, assessment methodologies within this community have evolved to a relatively stable and self-consistent state-of-practice. The M&S V&V plans within DoD should be developed to be consistent with this current state-of-practice. Definitions of terms are provided below[1] which are widely accepted and consistently (and literally) employed in most DoD M&S VV&A programs. These general definitions should be used in developing HWIL and distributed simulation VV&A programs:

- **VERIFICATION** - The process of determining that a model implementation accurately represents the developer's conceptual description and specifications ***(...is it what We intended?)***

- **VALIDATION** - The process of determining the degree to which a model *(or simulation)* is an accurate representation of the real world from the perspective of the intended uses of the model ***(...how well does it represent what We care about?)***

- **ACCREDITATION** - The official certification that a model or simulation is acceptable for use for a specific purpose ***(...should Our organization endorse this simulation?)***

Of special note, formal M&S management and VV&A directives and points-of-contact have been established within the Department of Defense. Some of these are indicated in ***Table 1.2-1***.

Table 1.2-1. Selected Department of Defense M&S VV&A Guidance.

DoD COMPONENT	POLICY GUIDANCE	POCs
Department of Defense	▪ Department of Defense Directive 5000.59 ▪ Department of Defense Directive 5000.61 ▪ Department of Defense VV&A Recommended Practices Guide	Defense Modeling and Simulation Office (DMSO)
Joint Chiefs of Staff	▪ Chairman of the Joint Chiefs of Staff Instruction 8104.01 ▪ Joint Staff Instruction 8510.01	Joint Chiefs of Staff (J-8)
US Army	▪ Army Regulation 5-11 ▪ Department of the Army Pamphlet 5-11	Army Modeling and Simulation Office (AMSO)
US Navy and Marine Corps	▪ Secretary of the Navy Instruction 5200.38 ▪ Secretary of the Navy Instruction 5200.40 ▪ Department of the Navy Modeling and Simulation VV&A Implementation Handbook	N81 Navy Modeling and Simulation Management Office (NAVMSMO)
US Air Force	▪ Air Force Instruction 16-1001	XOC

1. Department of Defense Directive 5000.59, "Modeling and Simulation (M&S) Management" (Washington, DC: January 4, 1994). Note that these definitions are tailored to M&S VV&A practice and differ in some significant ways from those cited in references dedicated to software development and software independent verification and validation (IV&V).

Table 1.2-1. Selected Department of Defense M&S VV&A Guidance.

DoD COMPONENT	POLICY GUIDANCE	POCs
Missile Defense Agency	▪ Missile Defense Agency Directive 5011	MDA / TEM

Complementary commercial VV&A guidance is available in technical papers, publications and standards promulgated by leading technical societies, including the American Institute of Aeronautics and Astronautics (AIAA), the Institute of Electrical and Electronics Engineers (IEEE), the International Standards Organization (ISO), the Military Operations Research Society (MORS), the Simulation Interoperability Standards Organization (SISO), and the Society for Computer Simulation International (SCS). Consequently, there exists adequate management, programmatic, and technical guidance for developing and implementing a reasonable program of assessment activities.

Although the DOD and component Services have similar practices and strategies for simulation verification and validation, their evolving formal policies stand at differing levels of maturity and they include a variety of guidance and procedures. However, a review of these policies and directives indicates a growing consensus on the necessity to subject M&S to a formal, structured V&V program. A convenient paradigm to view this set of M&S V&V guidance is provided in the Venn relational diagram in ***Figure 1.2-1***.

Of interest are not just the V&V requirements, methodologies and techniques that may be in common, but those special areas of interest that are resident within only a specific Service or agency. Any VV&A strategy must accommodate both overlapping and Service specific V&V guidance domains. Consequently, some tailoring of VV&A plans may be necessary to accommodate these differences. It is certainly necessary to understand evolving Service and DOD policies and practices to select M&S assessment strategies and activities that will be generally acceptable. These assessment activities and the associated VV&A planning documents will need to be tailored and coordinated through technical interchange meetings, reviews, and meetings with operational test agencies, and other government agencies to gain consensus on the overall VV&A program.

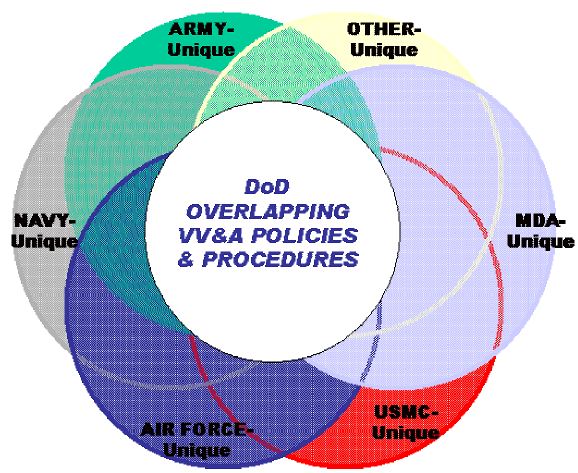

Figure 1.2-1. VV&A Policy Paradigm.

1.3 AUTHORS' EXPERIENCE.

The authors for this paper have considerable experience supporting HWIL and distributed simulations within the DoD, and whose VV&A experience and roles cover the gamut from M&S VV&A policy formation to V&V planning and activity execution.

Significantly, for this paper specific individuals from major Defense M&S enterprises were sought out to provide insight and contribute to the documentation of current practice within their institutions, and to address what initiatives the Department and component services must pursue to advance the state-of-practice:

- **William F. Waite** is co-founder and President of AEgis Technologies. In that role he directs a staff involved in a wide variety of modeling and simulation activities including simulation technologies evolution; simulation systems development; simulation verification, validation, and accreditation; simulation–based studies and analyses; and the development of hardware and software products supporting modern M&S practice.
- **Stephen J. Swenson** is the head of System Analysis for the Weapons Directorate at the Naval Undersea Warfare Center Division Newport (NUWCDIVNPT). Mr. Swenson provides technical and programmatic direction for modeling and simulation across the Weapons Directorate and specifically to NUWCDIVNPT's Weapons Analysis Facility (WAF). Mr. Swenson is dual-hatted and also leads the Navy M&S Standards Steering Group (MS3G) on behalf of the Navy Modeling and Simulation Management Office (NAVMSMO) and the Navy's transition to the High Level Architecture (HLA). The MS3G approved and recently re-approved Navy's VV&A Recommended Practices Implementation Handbook as an official Navy M&S standard.
- **Lt Col Seth Shepherd** is the Director, US Air Force Electronic Warfare Evaluation Simulator (AFEWES) Test Facility, assigned to the 412th Test Wing. In this role he is responsible for Hardware-in-the-Loop testing of blue Electronic Warfare (EW) systems as well as simulation development and VV&A activities at the AFEWES. Lt Col Shepherd has over 20 years experience in research & development, systems engineering, test & evaluation and program management primarily of infrared sensor systems and countermeasures.
- **Alexander C. Jolly** is Chief of the HWIL Simulations Functional Area in the Systems Simulation and Development Directorate, Research, Development, and Engineering Center (RDEC), U.S. Army Aviation and Missile Command. Mr. Jolly has over 40 years of engineering experience in a variety engineering fields, including the United Kingdom aerospace industry, a NATO military research establishment in the Netherlands, and the U.S. Army Aviation and Missile Command (and its predecessor Commands) in the United States. He is responsible for the HWIL simulation functional area within AMCOM to include the operation of the AMCOM RDEC Advanced Simulation Center (ASC) that provides hardware-in-the-loop (HWIL) simulation support to Program Executive Officers and Project Managers developing Army precision guided missiles and submunitions.
- **Robert M. Gravitz** is Director of Systems Engineering and Evaluation activities within AEgis Technologies and in this role directs M&S V&V tasks for several Major Defense Acquisition Programs (MDAPs) for several government agencies. Missile defense-related M&S VV&A programs Mr. Gravitz presently supports include the: Prime Consolidated Integration Laboratory (PCIL), Integrated

System Test Capability (ISTC), and Test Training, and Exercise Capability (TTEC) simulations for Ground-based Midcourse Defense (GMD); the Missile Defense System Exerciser (MDSE) and Wargame 2000 (WG2K) simulations for the Missile Defense Agency; and the Theater High Altitude Area Defense Systems Integration Laboratory (THAAD SIL) for AMCOM.

1.4 PAPER ORGANIZATION AND STRUCTURE

This paper considers verification, validation and accreditation as they relate to HWIL and distributed simulation enterprises. The paper is structured to speak:

- First, to VV&A processes, techniques and technologies for HWIL and distributed simulation systems (see Section 2). Key concepts and operational strategies set the stage for the follow-on discussion in which experiences of the Army, Navy, Air Force and Missile Defense Agency representatives will be shared.
- Then to major VV&A issues related to the HWIL and distributed simulation systems (see Section 3). This entails the identification of major issues that cut across application domain, major issues that are application-domain specific, and those lesser issues for which an ameliorative may be suggested.
- Subsequently, major VV&A research areas for HWIL and distributed simulation systems will be collectively addressed. Specific recommended research areas required for significant progress in HWIL and distributed simulation VV&A will be described. Our focus is the identification of feasible investments in VV&A research relating to processes, techniques, and tools that have the potential of reducing costs of execution and efficacy in operations (see Section 4).
- The VV&A of HWIL and distributed simulations and the challenges in their use are extended to the broader M&S domain and major points of the paper will be summarized and conclusions provided (see Section 5).
- A bibliography and list of references, which address HWIL and distributed simulation VV&A, is provided (see Section 6).
- Finally, author and contributor experiences relevant to HWIL and distributed simulation systems VV&A are noted (see Section 7).

II. HWIL AND DISTRIBUTED SIMULATION SYSTEMS VV&A PROCESSES, TECHNIQUES AND TECHNOLOGIES

In the sections that follow, we first address a few processes that we feel are generally relevant to the management of HWIL and distributed simulation VV&A and that are of particular value given the nature of this special class of simulations. Subsequently, we review the processes, techniques and technologies that characterize the VV&A operational environments of each of the contributing authors.

2.1 General HWIL and Distributed Simulation VV&A Management Strategies

We believe there are four key concepts and operational strategies that should comprise the foundation of HWIL and distributed simulation VV&A planning and execution. This set of elements is neither completely original, nor necessarily exhaustive of prospective M&S VV&A practice. And they are in any case more honored in the breach than in the observance - but they reflect conceptual paradigms that we believe are particularly effective in developing an executable plan to support HWIL and distributed simulation programs.

Each of the four concepts introduced herein are considered to be particularly relevant to the domain of hardware-in-the-loop and distributed simulation systems VV&A. In fact, the root cause of the concerns to which these strategies are responsive is largely one or another manifestation of the same circumstance relevant to many HWIL and distributed simulation systems, e.g.: size of simulation system, complexity of system (number and kinds of components and number and kinds of relationships among components), high investment cost, relatively long life-cycle, applications distributed over the life of the objective system, large teams, mixed agency and role participation over simulation system life-cycle.

Establishing a VV&A program formally and auditably traceable to accreditation requirements is particularly important when the M&S asset is expensive, long-lived and relatively versatile in it expected employment. Clearly identifying the verification and validation option space – what unit under test can reasonably be evaluated, by what means, to meet outstanding requirements – is more difficult and requires more care for large complex composites as are typical for both HWIL and distributed simulation systems. Considering precisely what is to be evaluated, in comparison to what referent and to what degree of compliance is necessary in order to scope V&V investment is extremely valuable in preserving a modicum of standardization of both execution and documentation when such a variety of V&V activities is to be performed by, commonly, a variety of participating agents. Finally, in environments where the simulation system developmental investment is already large and where collateral V&V investment is likely to be made progressively over the simulation asset's evolutionary life-cycle, a disciplined method for managing V&V investment in accordance with commensurate recovery in accreditation value is imperative.

2.1.1 Requirements Driven Program

Requirements for HWIL and distributed simulation verification and validation programs are best driven from the top-down, while V&V program execution is best built from the bottom-up. This chestnut of systems engineering is novel only insofar as its implementation is taken seriously. The goal of any V&V activity is to achieve the appropriate qualification of a given tool for a given purpose by a particular agency. It therefore makes sense to start by identifying the basis of such a judgmental decision, inferring the forms of evidence sufficient to support a positive outcome, and further deriving the means to generate and prepare for review and deliberation such evidence as is necessary and sufficient. The focus is not requirements compliance, but information gathering to support the government Accreditation Authority in accrediting the HWIL or distributed simulation and resultant data for use.

This requirements driven process is indicated in the illustration in ***Figure 2.1-1***, where accreditation information requirements flow downward. Implementation is through V&V agents (including SETA contractors, V&V contractors, Operational Test Agencies and Other Government Agencies (OGAs)) executing a suite of V&V assessment activities for particular M&S objects, or units-under-test (UUTs), to generate the necessary accreditation information data products and information to support user acceptance determinations. Particular steps in this ladder-down requirements process for VV&A are discussed in detail below.

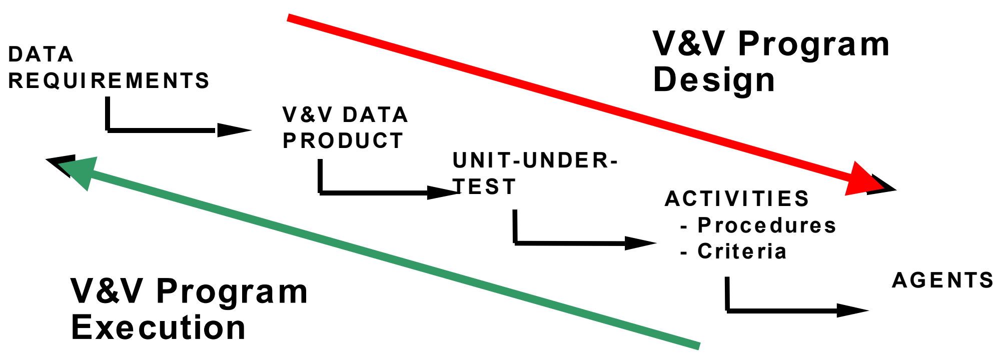

Figure 2.1-1. HWIL and Distributed Simulation V&V Requirements Planning and Execution.

Difficulties exist, of course, in anticipating all the user's criteria, and preferences for evidentiary support. Still, the expedience of assuming a position and building a program of action while preserving the audit trail of requirements serves as a ready basis for the tailoring of a practical, effective, and reasonably low-risk strategy for HWIL and distributed simulation VV&A programs.

2.1.2 V&V Evaluation Activity Space

The second significant concept recommended for use during HWIL and distributed simulation VV&A program definition is also a familiar one - it is the systems engineer's multi-dimensional view of the enterprise whose dimensions exhaust the important attributes of the conceptual space. Here we posit an "evaluation space" whose (relatively orthogonal) dimensions consist of: 1) V&V activities, 2) V&V agents, and 3) units-under-test. The points or cells in this evaluation space represent the V&V data products that are produced when a V&V agent carries out a V&V activity to evaluate a particular unit-under-test. This space is indicated (imperfectly) in ***Figure 2.1-2***.

Each dimension is described in detail in the paragraphs that follow, after which the use of this construct in mapping-out and populating a practical V&V plan-of-action is indicated.

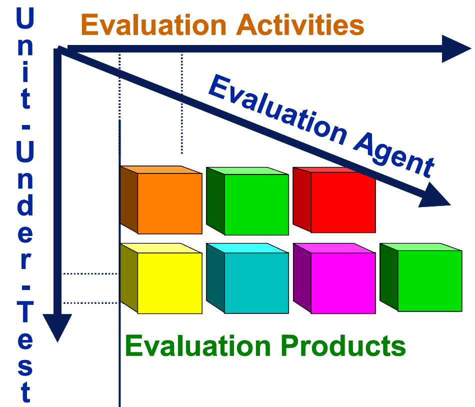

Figure 2.1-2. V&V Evaluation Activity Space.

The V&V products comprise the evidence for user acceptance and formal accreditation. The evaluation product requirements can be identified through development of a select set of candidate activities that are coordinated with potential users and Accreditation Agencies. The anticipated classes of data products that may be considered in the accreditation decision include:

1) *SW V&V Administrative Documentation*; i.e., V&V Plan, summary V&V Reports.
2) *Simulation System Documentation*; i.e., System Specifications, System Design Documents, and Software Requirements Specifications and related documentation, CM Plan, User's Guide, Training Materials, etc.).
3) *Evaluation Documentation*; including design documentation; Integration and Test Plans, component descriptions, and Test Activity Assessment Reports generated as a consequence of executing the VV&A Plan.
4) *Other Technical Reports and Data* generated by other evaluations (Requirements Analyses, CM Reviews, Subject Matter Expert Evaluations, V&V Analysis Reports, etc.).

Units-under-test (UUTs) are those components of the HWIL or distributed simulation to which V&V evaluation activities are applied and upon which judgments are made. Because HWIL and distributed simulations may be a system simulation, and, or a set of system specific component models, several entities may exist which will need to be verified and validated to establish user confidence and credibility of the simulation data products. Candidate UUT components, or facets of a HWIL or distributed simulation are indicated by the items enumerated in ***Figure 2.1-3***.

SYSTEM SOFTWARE
- System Configuration Code
- Framework
- Common Model Set Code

SYSTEM CAPABILITY
- Experiment Preparation
- Experiment Execution
- Experiment Analysis

ANALYSIS TOOLS

SYSTEM MODELS
- Common Model Set Algorithms
- Specific System Representations (SSRs)

DATA
- Rulesets
- Characteristics Data
- Gameboard Data
- Scenarios

DOCUMENTATION

Figure 2.1-3. Candidate HWIL UUTs.

Naturally, the design of V&V exercise activities depends on the nature of the UUT (for example, we can validate analytical models, verify code, validate system models, certify (validate) input data, etc.). Because the variety of entities that comprise a HWIL or distributed simulation is quite large, and because the items are themselves so disparate, a variety of evaluation procedures are required. Explicit identification of UUTs within the VV&A Plan is therefore imperative.

Activities are selected V&V techniques and assessment procedures to be applied to relevant HWIL or distributed simulation UUTs to generate V&V data of interest and upon which acceptance criteria can be established. Classes of potential assessment activities include those indicated in the list provided in ***Figure 2.1-4***.

Several considerations are pertinent to HWIL and distributed VV&A activity planning which are extensible to M&S VV&A planning in general.

First, activity definition requires careful specification of the evaluation procedures and criteria. Second, the details of activity specification effectively define the V&V program. Activity flow and duration determines the program schedule. The choice of assessment activities determines the level-of-effort (LOE) and associated resource requirements. Finally, *every* V&V assessment activity should be required to yield a valuable data product that facilitates user understanding, acceptance and accreditation.

Agents are those principals that serve at the behest of the simulation sponsor and, or other Accrediting Activity; executes the planned V&V and test assessments; and generates the reports that serve to document the activity. A wide variety of agents are available to the HWIL and distributed simulation sponsor that can contribute to the execution of V&V activities, which comprise the VV&A program. Each agent should be assigned a clearly defined role. Each should be selected based on their capability to serve as the appropriate executor of one of more activities.

For example, while the simulation sponsor may be responsible for overall V&V program strategy and oversight, a V&V Agent (contractor) can conduct a wide range of independent verification and validation activities for the HWIL or distributed simulation program. Collectively, the V&V organization might be expected to conduct documentation reviews, code reviews and independent software tests; provide subject matter expert (SME) support for simulation-to-simulation comparisons; and conduct peer reviews and hands-on evaluations. In addition, the simulation developer can provide systematic product development, and be directed by the simulation sponsor to execute selected system, software, or model verification and validation activities, as well as develop the associated documentation. In addition, a SETA contractor may be directed to conduct system and design document reviews. Other government agencies, and their support contractor organizations may provide subject-matter-experts (SMEs) for reviews and engineering analysis if requested. Operational Test Activities may contribute to the VV&A effort by contributing to the development of the overall VV&A program strategy, and may elect to conduct independent data certification and provide SME support.

Coordination among this diverse set of potential V&V agents is required to execute a balanced, comprehensive VV&A program for HWIL and distributed simulation

VERIFICATION:	VALIDATION:
- Documentation Assessment	- Sensitivity Analyses
- Requirements Trace	- Face Validation
- Methodology Review	- Benchmarking
- Code Walkthrough	- Test / Field Data Comparison
- Data Certification...	- Peer / Red-Team Review...

Figure 2.1-4. Potential V&V Activity Classes.

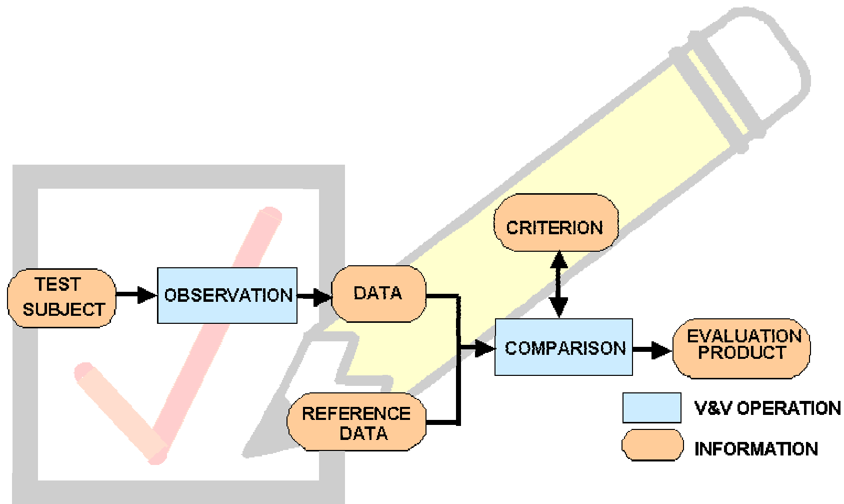

Figure 2.1-5. Generic Evaluation Process Model.

systems. A *Lead* V&V Agent should be assigned responsibility for coordinating the overall VV&A program execution.

2.1.3 Evaluation Kernel Process-Model

Verification and validation are forms of evaluation or judgment regarding the merit of a model and simulation tool with respect to some specific application or class of application. It entails evaluation of components or facets of the tool, and eventually a net assessment of the entire tool. The ultimate result is a management judgment, suitably constrained or qualified, on the suitability of the tool for use (i.e., accreditation). A generic evaluation process model is indicated in the diagram of ***Figure 2.1-5***.

This activity / data flow diagram illustrates the components of an evaluation process which is applicable to any evaluation enterprise, but is particularly pertinent to HWIL and distributed simulation evaluations. This evaluation process involves the following components and associated activities: a) an observation of a M&S UUT and its attributes of particular interest; b) a comparison of derived data pertinent to the UUT under consideration to reference data established by independent means; c) subject to criteria for acceptance; and d) generation of an evaluation product (results).

The activities undertaken in support of the HWIL or distributed simulation evaluation process should be tailored to specific UUTs for the application domain. Explicit specification of the acceptance criteria is imperative for tailoring and applying the generic V&V evaluation process to the HWIL or distributed simulation components.

The determination of evaluation criteria values (i.e., what constitutes "good enough") can be derived logically from the need for user confidence in the respective M&S characteristics. The evaluation agent should develop evaluation criteria for consideration and acceptance by the simulation sponsor, Accreditation Authority, and other government agencies.

This comparison of UUT data and reference data to appropriate criteria can be supported when there is consensus for the selected criteria within the program participants. When consensus cannot be obtained, the use of a criterion in the evaluation process can also be based on an individual agency's criteria; e.g. AFOTEC and ATEC will develop their accreditation criteria independently. Data for assessment activities that support characterization of the UUT should be collected, archived, and disseminated by the simulation sponsor to support these independent findings.

2.1.4 Managed Investment

Managed investment is the execution, from all the possible candidate V&V activities, of a carefully selected subset of V&V activities:

1) ***Offering the "best return on investment"*** by providing the essential information necessary for V&V reports findings, and
2) ***Providing the required evidence*** supporting the accreditation review decisions of Service and DOD agencies and activities.

As a consequence, cost as an independent variable was considered during the selection and execution of the V&V assessment activities. The V&V activities subset is chosen based upon the:

- Assessment data needs of the Accreditation Authority,
- Realities of the program (schedule), and
- Fixed resources (budget) available for assessment and V&V activities.

As the most cost-effective set of cells within the space of possible V&V activities, the actual evaluation subset of V&V activities constitutes a near optimal investment. The next cell implemented is the one providing the "best return on investment" for the expended resource (time or money) in terms of the value associated with the assessment data product that was developed. This is graphically illustrated in ***Figure 2.1-6***.

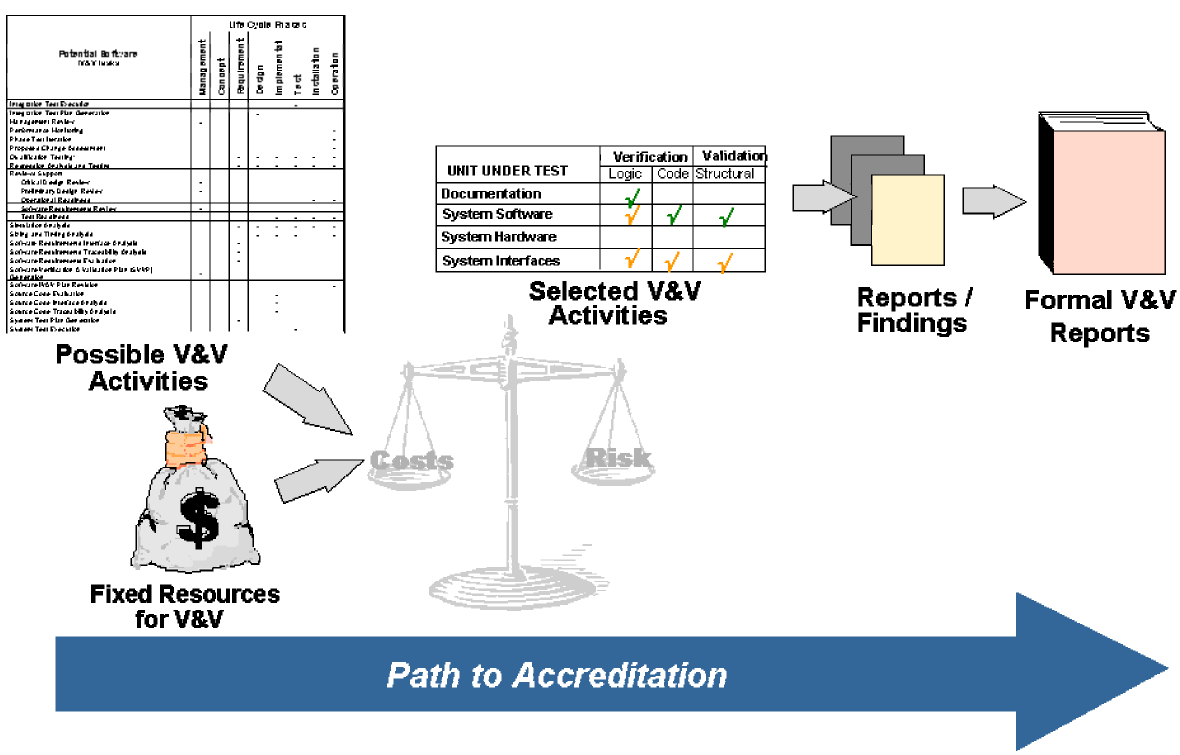

Figure 2.1-6. Managed Investment Strategy for M&S VV&A.

A managed investment (progressive outlay) strategy addresses the problem of specifying scope and detail of V&V activities and allows for a near-optimal investment for V&V activities and products for an economically constrained environment. This investment strategy provides for a deliberate and progressive outlay of resources that garner the information necessary to support accreditation decisions. Thus, an actual V&V evaluation suite can be identified which is the most cost-effective within the space of possible candidate activities. This sub-domain constitutes an optimal investment in V&V for the HWIL or distributed simulation.

This is our suggested practice. It is consistent with current policy guidance.

But, now let us consider the actual VV&A operations and state-of-practice through examination of representative HWIL and distributed simulation program experiences within the DoD component services. Detailed below are the actual experiences and processes in-use within selected HWIL and distributed simulation facilities of the Army (see section 2.2), Navy (see section 2.3), Air Force (see section 2.4), and Missile Defense Agency (see section 2.5). An examination of the VV&A processes endemic to each will be detailed in these sections.

2.2 US Army AMCOM HWIL & Distributed Simulation Systems

The Systems Simulation and Development Directorate (SSDD) of the Research, Development, and Engineering Center (RDEC) of the U.S. Army Aviation and Missile Command (AMCOM) provides a range of simulation support services to Army missile and aviation developers.

2.2.1 Context

The mission of SSDD is stated (in part) as *"…to assist in the evaluation and analysis of new weapon systems, provide technical and simulation support to all elements of the parent organization, project managers, and other government agencies. To conduct weapon systems research, exploratory and advanced development and provide engineering and scientific expertise*." Among the topics pursued by SSDD are HWIL simulation of missiles and submunitions and constructive, virtual, and live simulations of multi-entity, force-on-force, large-scale distributed simulations for the evaluation of specific weapon systems in a battlefield and tactical context. While the value of unvalidated simulations - particularly for design trade-off studies, obtaining insight into system performance during preliminary studies, systems integration, flight test support, and initial checkout - is recognized within SSDD, simulations which are to be used throughout the life cycle of weapon systems and on which formal performance assessments and acquisition decisions are to be based require a rigorous validation for the full benefit to be obtained from the considerable investment presently being made in simulation support.

2.2.2 Where Is AMCOM RDEC Today?

a) Description of Objective Systems.

SSDD HWIL simulation activities range from applications to air-surface submunitions and missiles (examples being BAT and LONGBOW HELLFIRE), air defense surface-air weapons (STINGER, PATRIOT PAC-3) to ballistic missile defense systems (THAAD, Ground-based Midcourse Defense Segment).

These HWIL simulation activities are conducted in the AMRDEC Advanced Simulation Center (ASC) that consists of 10 individual simulation facilities. An illustration representing a range of activities and equipment in the ASC is shown in ***Figure 2.2-1.***

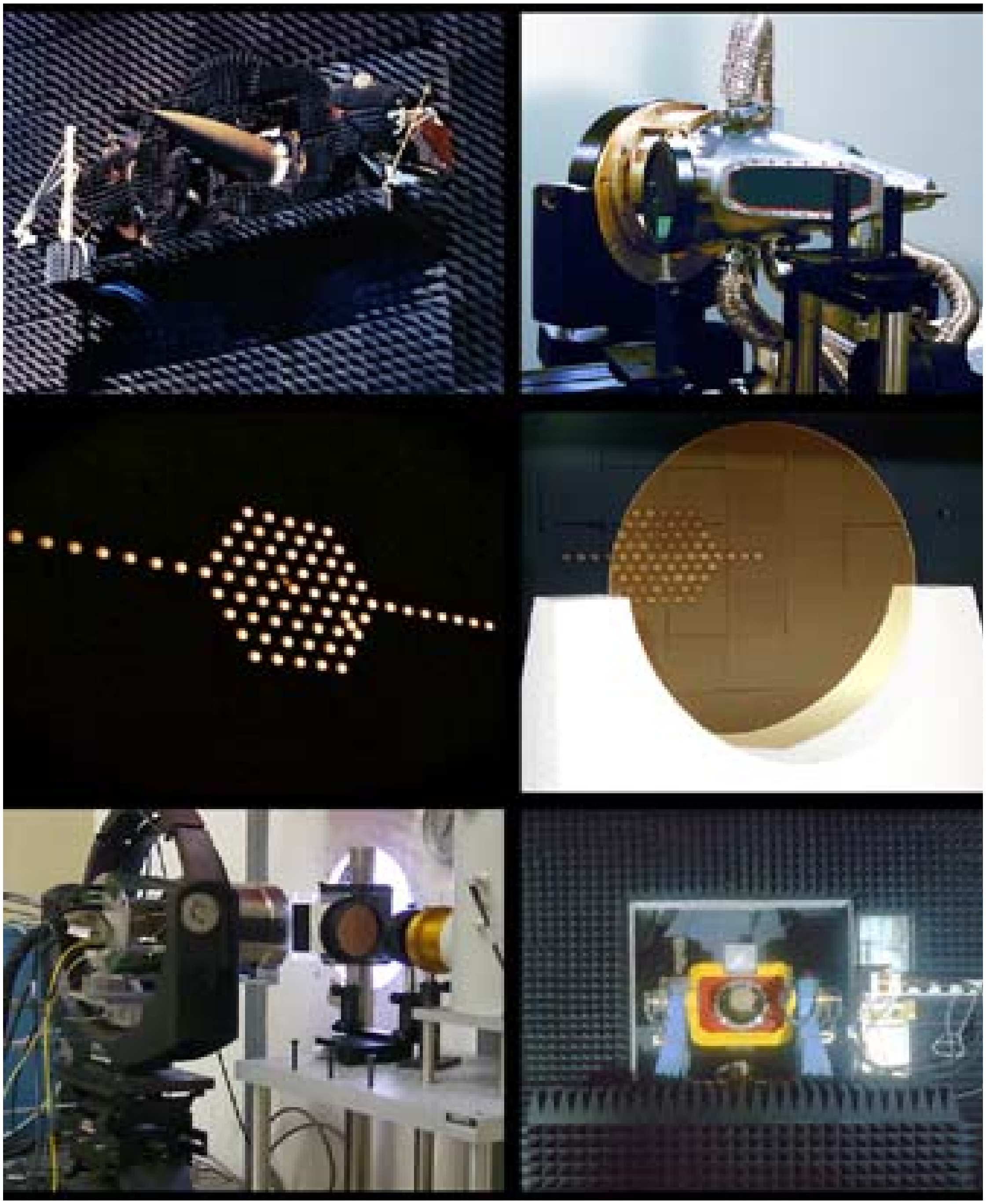

Figure 2.2-1. ASC Activities and Equipment.

Figure 2.2-2 contains a block diagram of one of the ASC facilities designed for evaluating multi-spectral (millimeter wave RF and imaging infrared) missiles and submunitions and illustrates the general concept of all ASC facilities. Distributed simulations associated with the Advanced Prototyping, Engineering, and eXperimentation (APEX) Laboratory, which consist of federated simulations interacting with federates at other Army and DoD facilities using Distributed Interactive Simulation (DIS) and High Level Architecture (HLA) standards, to provide an integrated virtual

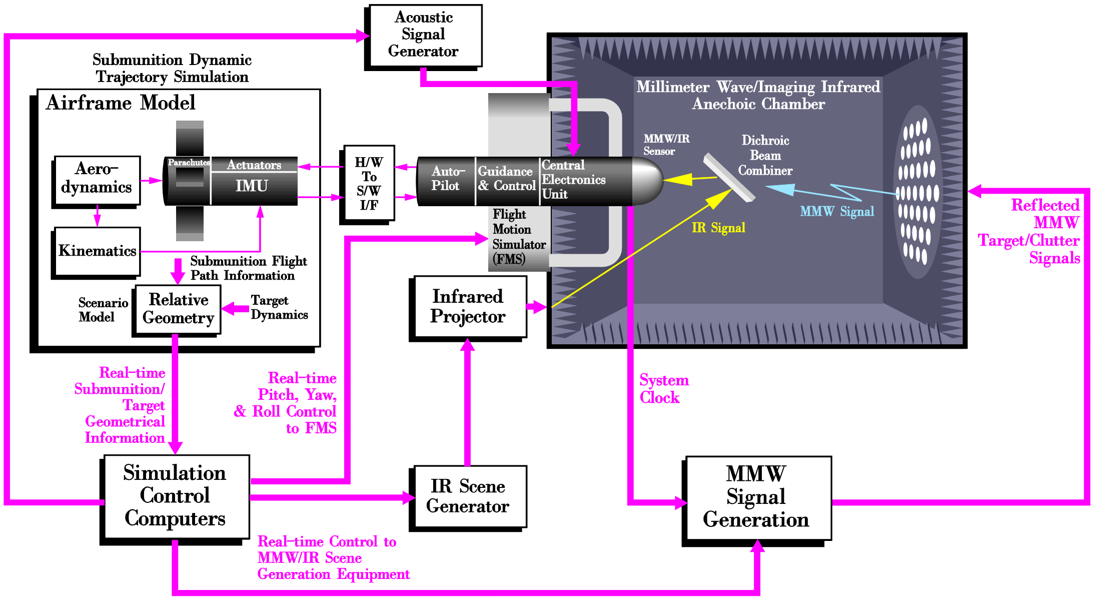

Figure 2.2-2. Example ASC HWIL Simulation Block Diagram.

battlefield for system performance and battlefield effectiveness studies. Activities within the APEX focus on man-in-the-loop evaluations for aviation and missile systems. Federating with other Army RDECs provides functional expert fidelity for their areas of expertise. Examples of APEX systems evaluated include Utility Helicopter-Modernization, Virtual Cockpit Optimization Program (VCOP), Unmanned Ground Vehicle (UGV), Joint Advanced Weapon System (JAWS), and Common Missile. The APEX also evaluates integrated system concepts such as the Rapid Force Projection Initiative (RFPI). Distributed simulation activities also include a HWIL simulation where ground equipment (launcher, fire control, BMC3) is located remotely from the missile HWIL. An illustrative diagram of the APEX laboratory is shown in ***Figure 2.2-3***.

b) Fundamental Strategies For Business Operations.

SSDD provides simulation support to a wide range of weapon system developers, including Army project managers and other customers to assist in system design and acquisition decisions. M&S VV&A must be sufficient to address the relevant design and acquisition issues through experimentation and analysis. Mechanisms exist for implementing agreements with commercial and private industry organizations for cooperative work or for the provision of reimbursable services using Army simulation and test facilities. Simulation support requirements to project managers are usually defined by a Simulation Support Plan with an associated Verification, Validation and Accreditation (VV&A) Plan. Both the Simulation Support Plan and VV&A Plan are tailored to the specific weapon system under development, and are intended to apply throughout the system life cycle, from initial concept and risk reduction phases through fielding and final disposition. Implementation of the Simulation Support and VV&A Plans is overseen by a Simulation Working Group (or IPT) with membership comprised of: engineering staff from the Project Manager's office; AMCOM RDEC SSDD personnel; prime contractor/vendor personnel; support contractors; test range T&E and

Figure 2.2-3. APEX Laboratory.

Project Office T&E staff; and the Army independent evaluator (usually a representative from the Army Test and Evaluation Command - ATEC).

c) Techniques & Technologies.

Wherever possible, validation of HWIL simulations is based on measured data from a range of measurement programs, including target signature measurements, captive-carry of sensors and seekers, and sled and flight tests of missiles and submunitions. Test programs are structured to yield data that support the simulation validation process. The validation process for an overall system simulation is then a piecewise operation: the system is divided into sub-systems (or "modules" corresponding to each sub-system) and a validation process is applied to each sub-system individually before applying an overall system validation process. In general terms, sub-systems will typically include: target signatures and target background environments models and hardware (constituting what is also known as scene generators and scene projectors); a target motion model (for most simulations, target motion is specified a-priori, but when comparing flight tests against simulation results the actual target position time history as measured on the test range should be input to the overall simulation); target sensor(s) for those systems in which a target presence is sensed; a target tracking sub-system (for those weapons which track the target position, direction, and their rates of change); a guidance and navigation sub-system (including sensors such as inertial measurement units, gyros, accelerometers, and air data sensors); six degrees-of-freedom motion models (6DOF) including mass properties, aerodynamic forces and moments, and propellant models (including lateral thrusters for those systems using this form of lateral motion control); logic state system for mode and state control of all sub-systems; and HWIL simulation hardware effects (flight table response, interface latencies, effects of target signal generation compromises, synthetic line-of-sight effects if used in the simulation). The validation process then compares simulation data with measured data to determine whether the validation criteria are met (see paragraph e in this sub-section). Note that the overall system simulation may need to be executed to provide sub-system data, in which case parameter values for the specific test conditions need to be used in the simulation. The validation process for some sub-systems may involve "driving" the sub-system simulation with measured time variable signals.

VV&A approaches for distributed simulations vary widely because of the wide range of models and simulations in use at AMRDEC facilities. Verification of engineering-level models is conducted against actual system software or test data where possible, or compared to the actual hardware article, when available. Validation of simulation software and performance is done through input of certified data, review of output data and behaviors, and comparison to real system performance to the degree that it is known. Much of the M&S that AMRDEC conducts is prototypical of undeveloped systems, in which case V&V is based more on physical principles, boundary conditions, draft designs, subject matter expertise, and extrapolation of existing data. Legacy models are often combined and integrated with new developments. Consequently, after each individual model or simulation is verified and validated, the integrated suite must undergo V&V to ensure a level playing field, data consistency, synchronization, and federation-level performance. Accreditation is usually performed informally for a specific instance of a distributed simulation experiment or analysis series, based on customer needs and measures of effectiveness. An example of these levels of VV&A would be the development of a virtual prototype of a system. The virtual prototype must undergo VV&A individually, but then must also undergo additional VV&A within the integrated battlefield environment, as the integration with other representative systems in the simulation could cause unexpected behaviors.

d) Maturity.

(1) Existing AMCOM HWIL and Distributed Simulation Validation Processes.

The VV&A processes for HWIL simulations are illustrated in general terms in the following diagram (see ***Figure 2.2-4***) with a specific reference to the Army Tactical Missile System Block II):

Verification is, somewhat arguably, a more straightforward process than validation. It involves ensuring that the simulation is implemented correctly by various means, including design and code "walkthroughs" at specific points in the simulation development program, numerical calculation checks, "sanity" checks, isolation of subsystems and measurement of their responses to prescribed standard inputs such as sine waves and square wave impulses, "handshaking" across interfaces, and timing checks. For HWIL simulations, the verification of system timing, synchronization and time latency compensation is possibly the most difficult part of verification and always requires special attention. Validation is a more system-specific process, with approaches tailored to the characteristics of each specific weapon system. Nevertheless, a brief discussion of a typical procedure is given in the preceding item c, above.

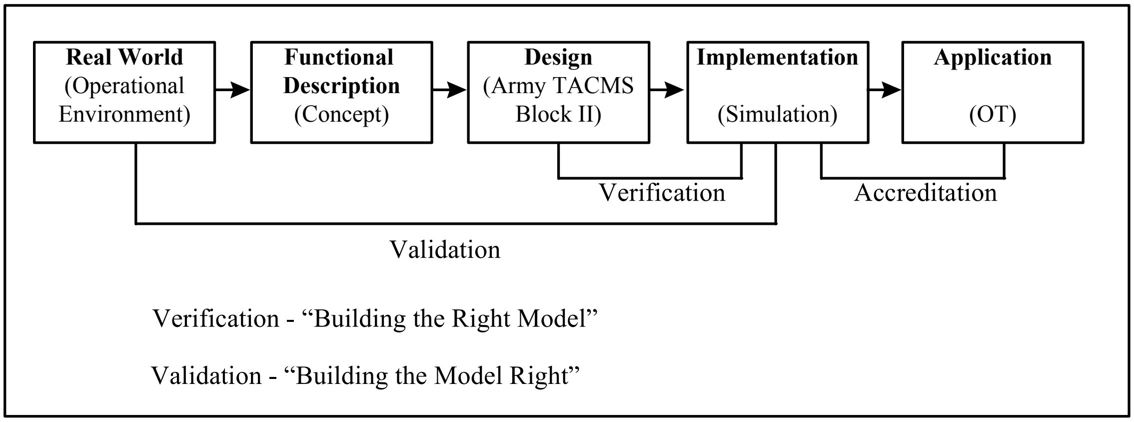

Figure 2.2-4. US Army AMCOM HWIL VV&A Process.

AMRDEC distributed simulation VV&A processes have their roots in the AMSAA Anti-Armor (A^2) ATD experiment series, which was conducted in 1993-1996 to establish analytical validity to virtual battlefield experimentation. These processes were refined to support the Rapid Force Projection Initiative (RFPI) program in 1994-1998, and are now integral to simulation development and experimental design for all APEX customers. VV&A for these experiments focused on evaluation of level playing field, system timelines and individual performance.

(2) Validation Procedures And Tools

Validation procedures for HWIL simulations within SSDD have not been systematized such that a general “across the board” procedure can be applied to any or all weapon systems. While Army Regulation AR 5-11 provides guidance for simulation VV&A, it is not specific enough for anything but the highest-level, general guidance. Validation procedures for some specific sub-systems, however, such as target signatures and backgrounds, target scene generators and 6-DOF modules, have enough commonality across multiple systems that they may benefit from standardized procedures and tools. At present, such tools have not been developed for general use but the requirements of each Simulation and Support Plan and VV&A Plan are addressed individually. Another particular area of HWIL simulation validation that may be amenable to standardization is that of calibration of signal generation and projection systems for missile and submunition guidance signals.

Distributive simulation VV&A efforts within the APEX lab utilizes COTS tools to visualize and analyze virtual environment events and visual models, as well as the AMRDEC-developed Data Collection and Analysis Tool (DCAT) to monitor real-time and post-experiment battlefield statistics. COTS tools are also used to monitor real-time HLA performance. The DCAT is a real-time data capture and analysis application that collects data from a DIS or HLA exercise and provides feedback to the user concerning system performance. The DCAT provides a user the ability to monitor data as it is captured by the application to perform exercise debugging. An SQL database is created on the fly that is used to generate collated information for the user. In addition, DCAT is capable of providing the user with real-time and post-processed data from the exercise.

The data is relayed to the user in a variety of easily understood and tailored graphs and charts. It is most often associated with the capability to evaluate user-definable measures of effectiveness (MOEs) with near real-time feedback. It allows the user to evaluate combat effectiveness, observe system timelines, and perform validation of simulators/simulations.

(3) The Consequential Effects Of This Circumstance

Consequently, for VV&A of HWIL simulations there is scope for attempting to standardize simulation validation to some extent. The standardization would include an associated development of reusable and standard tools, while recognizing that the procedures and tools must retain enough flexibility to accommodate differences among the applications they are intended to support.

For distributed simulation VV&A, the use of tools and processes has allowed the APEX lab to tailor the VV&A process, rely on previous legacy V&V, and also rely on informal accreditation.

e) Measures of Success.

The most basic measure of success of a validation effort is that of a successful accreditation by the accrediting agent for the subject simulation. In order for accreditation to occur, the verification and validation processes must be supported by complete documentation so that an auditing trail can be readily established and inspected. Individual validation processes require the specification of criteria by which the success of the validation process can be measured. Satisfaction of these criteria then becomes the basis for establishing a successful validation. In order to determine the validation criteria it is necessary to select "critical parameters" for comparison between simulation and measured data. The selection of the critical parameters is primarily a matter of engineering judgment based on a detailed knowledge of the system being simulated, although the common modules and sub-systems mentioned above often will have common critical parameters identified.

Having selected the critical parameters, it is then necessary to select the acceptable ranges of variation between the simulated and measured parameter values within which the validity of the sub-system or overall system can be accepted or rejected. Clearly, the ranges of permitted variation depend on the characteristics of each parameter and an estimate of the measurement accuracy for the test data. Some parameters in the simulation will be defined as stochastic and be represented by statistical distributions with prescribed means, medians, and standard deviations, thus giving rise to system level results (typically target intercept miss distances for missiles and submunitions) which will be statistical in nature. Evaluation of system-level results is then based on Monte Carlo sampling and critical parameter ranges can be defined in statistical terms. Parenthetically, it may be noted that stochastic parameters are often the least well-defined input data to the simulation models and quite often are among the parameters that must be adjusted to achieve validation.

A determined effort should be made during the course of a weapon system program to acquire data to provide accurate supporting data for these parameters and statistical distributions. When a HWIL simulation is implemented, the hardware itself will in effect be a single sample from a set of parameters governed by a distribution of manufacturing and design tolerances and the system model should attempt to take this into account by including parameters which permit adjustments to the models. However, "adjustable" parameters must be used with care, remembering Einstein's "cosmological constant" in his general theory of relativity that was included to permit his theory to accord with the then-current steady-state theory of the origin of the universe. Without that "fudge factor" the general theory actually predicted the "big-bang" origin of the universe, long before Penzias and Wilson discovered the cosmic microwave background remnant.

Successful completion of the validation process (i.e., the validation criteria are met for the comparison of the selected set of parameters) leads to the accreditation process. Clearly, an identifiable and complete documentation trail of the verification and validation processes is required to establish the accreditation and, once achieved, accreditation allows the simulation results to be accepted as credible performance predictors of the subject system. A further effect of having achieved accreditation is that the simulation then requires that a strict configuration control process be applied, since any changes to the simulation may invalidate the current level of validation. For man-in-the-loop simulations, the key measure of success is often the equivalent of a Turing test, where soldier participants are unable to distinguish the difference between virtual and real entities in a live/virtual experiment for the parameters of interest, such as controls, functions, digital messages, weapon performance, etc. For analytical purposes, correlation of battlefield results with constructive models has proved to be an effective measure. The ultimate measure of success is approval by the accrediting agent. As in HWIL, parameters are set through engineering judgment and tested using the methods described above. The ability to define and assess MOEs within the DCAT streamlines this process considerably.

f) Synopsis / Summary.

Over the course of the past 25 or so years, SSDD has implemented a large number of simulations of various types. Of these, a significant number have undergone a formal VV&A process. However, in each case the validation has been tailored for the specific subject weapon system. The determining factor in whether VV&A is applied centers on the longevity of the system's life cycle and the level of funding for the system. In other cases, validation has been limited to informal comparison of simulation results with limited flight test data, particularly in the case of flight failures when a HWIL simulation is used to replicate the failure mechanism. APEX Lab VV&A experience can be traced over the last eight years, beginning with the A2 ATD program, through the stringent live/virtual requirements of RFPI, and into current HLA federation initiatives. During A2 ATD, AMSAA/ATEC experts spent hours after each record run comparing test results to predictions, reviewing the run for anomalies, and cross-referencing V&V tests, before accrediting each run as valid. This led the APEX lab to develop DCAT, which automated the battlefield statistics process to monitor the experiment in real-time and even make performance corrections on-the-fly, a critical capability when performing live/virtual experiments with 1500 soldiers in the field. Now this automated process is facilitating a variety of customers, providing analysis-quality results from virtual environments.

2.2.3 Where Is AMCOM RDEC Going?

As a response to the impetus provided by the current emphasis in the Army on Simulation-Based Acquisition, SSDD has reviewed its entire approach to simulation and modeling and is in the process of implementing a Collaborative Design Approach (CDA) and a Common Simulation Framework (CSF). The objective of the former is to enable multiple entities to exchange design data for particular missile and submunition development projects, and for the latter, to devise a common structure for simulations such that mutual re-hosting of vendors' and Army simulations will be readily achievable. With a common structure for various simulations, a more standardized approach to VV&A will become possible. Within the last two years, the APEX Lab has been established as a key element of the Army Materiel Command (AMC) RDEC Federation. RDEC Federation experimentation is conducted across the DREN using HLA to integrate commodity simulations at eight locations across the country. This capability has stressed the VV&A process by introducing critical network performance issues into the overall simulation performance problem. These issues have so limited the federated analysis capability that they have become the top priority for distributed simulation VV&A in the near-term.

a) Intention and Rationale.

The distributed nature of the approach to VV&A in SSDD (i.e., VV&A Plans for each system or project supported are derived and implemented independently) is such that a coordinated effort to improve the process is not easy to implement. The intention of the CSF is that a common approach to validation will arise from the effort and that this common approach will result in improved an overall validation process. As the APEX Lab becomes more involved in collaborative experimentation, distributed simulation VV&A will grow into a multi-agency activity with the potential for outside oversight or review by organizations such as AMSAA and TRAC. This is already apparent in scenario implementation and data certification, but could broaden across the entire process.

b) How We Are Going To Get There?

For HWIL simulations, a process of re-education of the engineering personnel performing the simulations to demonstrate the benefits of an improved validation process will be necessary. Attempts to impose new processes from above will be counter-productive. For the distributed simulations conducted by APEX, changes in the process will be driven by centralized analysis requirements from organizations such as Future Combat Systems and the Objective Force Task Force.

c) Expectations?

If the new validation processes are genuinely an improvement they will find ready acceptance among the simulation practitioners of SSDD. Virtual experimentation will continue to be regarded as suspect for analysis by the traditional analysis community in the near future, with most acceptance in the area of virtual prototyping and MANPRINT, and the least acceptance in performance prediction of weapon systems. Solid VV&A practices will help in counteracting this attitude.

d) Why Do We Want To Get There?

Improved validation processes will significantly improve the capabilities of SSDD and hence benefit the Army's Simulation-Based Acquisition initiative. However, until we can establish the validity of virtual environments for analysis, man-in-the-loop effects will not be fully considered in acquisition decisions.

e) What Do We Gain From Getting There?

Among the gains of improving VV&A processes is better service to SSDD customers in the form of improved simulation support, including faster response and greater credibility for simulation results. A fully accredited virtual man-in-the-loop capability provides the nearest representation to the tactical environment for future technologies that do not yet have real hardware.

2.2.4 What Is The Risk?

HWIL and distributed simulations have unique, system-specific characteristics and real-time relationships that may prevent across-the-board VV&A improvements. In attempting to formalize the VV&A process beyond its present status, a risk exists that considerable time and effort may be spent on experimenting with new methods and techniques without resulting in any improvements over present methods. The highest risks in APEX Lab VV&A are associated with long-haul distributed simulation, as discussed in section 3.1 below.

An additional risk lies in the funding issue. VV&A requires an investment of resources over a considerable time span; and it requires a steadiness of purpose and continuity in order to reap a reasonable return. The risk lies in erratic funding levels for VV&A activities.

2.3 Department of Navy HWIL & Distributed Simulation Systems

The author of this section is "dual hatted." He looks at Hardware-In-The-Loop (HWIL) simulation and VV&A from the Navy perspective as OPNAV N60MT1 responsible for Standards Development in the Navy M&S Management Office (NAVMSMO). He is also the Head, Systems Analysis, Code 801, Naval Undersea Warfare Center (NUWC) Division, Newport and former Head, Weapons Analysis Facility (WAF) and Lifecycle Support Facility. He is still involved with the WAF in the capacity of technical advisor.

Accordingly, in this portion of the paper, we will look at the Department of Navy from two very different perspectives. First, attention will be given to the Weapons Analysis Facility (WAF) – a hardware-in-the-loop (HWIL) simulation for undersea weapon systems (specifically torpedoes and countermeasures). Second, we will attempt to address the broader Navy concerns spanning the full spectrum of simulations encountered within that Department.

2.3.1 Context

The Navy is a broad and varied community embracing an extremely large mission space and spanning many operational domains. Navy is unique in that it operates in the air, on the land, on the sea, and under the sea. Submarines take advantage of the “opaqueness” of the undersea environment to maintain stealth. Submarines use their stealth to provide a precision strike capability, and to hunt and destroy, while attempting to avoid being destroyed by other submarines and surface ships. Surface ships provide forward deployed presence and use highly sophisticated sensor and weapon systems to engage air, surface and sub-surface targets. Naval aircraft missions include providing first and forward strike, air protection for the battlegroup, and airborne surveillance capability. Special operation forces are deployed in various ways from the littoral to carry out clandestine, land-based assignments. And the Marine Corps is the nation’s expeditionary force and, as such, is the “pointy end of the spear” for the land battle.

In order to perform effectively against highly capable threats while immersed deeply within their operational and environmental context, Naval platforms are necessarily sophisticated, robust, and interdependent systems of systems – i.e. sensors, weapons, human machine interfaces, communications networks, and people. The torpedo, for example, gets its firing solution from the weapons team based on guidance from the sonar team using the submarine sonar dome, towed arrays and wide-aperture flank arrays. Once fired, the weapon must – from within its refractive, reverberant, multi-path acoustic environment – detect, classify, localize, and finally engage and destroy its target.

A recent Discovery Channel documentary identified both the Naval Aircraft Carrier and the Ballistic Missile Submarine as two of the most complex systems ever conceived and built by man. Table 2.3-1 is a poignant and quantifiable illustration of the magnitude of the complexity of Naval systems[2].

2. Extracted from Virginia Class Submarine Program Office (PMS450) brief titled: “Overview of the Approach, Processes, Tools and Technologies Used to Develop the New Attack Submarine.”

Table 2.3-1. A Comparison of System Complexity Across Domains.

ATTRIBUTES	M-1 MAIN BATTLE TANK	BOEING 777 AIRPLANE	VIRGINIA SSN
Weight (tons)	65	250	7,000
Length (feet)	25	200	360
Number of systems	25	40	200
Number of components	200	35	20,000
Number of suppliers	600	550	3,600
Crew size	4	10	133
Patrol duration (hrs)	24	8 to 14	2,000
Number of parts to assemble	14,000	100,000	1,000,000
Number of man-hours / unit to assemble	5,500	50,000	8,000,000
Production time (months)	7.5	14 ('97)	55
Production rate (units/yr)	600	72 ('97)	2 to 3

We've dealt, albeit briefly, with the Navy's operational context, its current and future technical and operational direction and the emerging fiscal environment. We will now round out the Navy context with a discussion of Navy culture. Technical papers with a decided application-orientation must consider the cultural context in which technical decisions and technical changes are made. This is especially true for the Navy where there is no uniformed acquisition force, while program offices and resource sponsors are, more times than not, headed and manned by uniformed, operational personnel. The Navy culture is as varied as its mission but there are certain key cultural characteristics that are pervasive across the Department.

There's an old proverb that says that your best characteristic is also your worst. Since the days of John Paul Jones and *Bon Homme Richard,* the United States Navy has enjoyed a long and distinguished history of independence, tradition, and "damn the torpedoes" pragmatism. While independence, tradition, and pragmatism have served our nation's Navy well and have made it the most capable Navy in history, they have also created an environment with some interesting challenges. Independence can often mean, "I know best"; tradition can often mean, "we've always done it this way"; and, pragmatism can often mean, "the ends justifies the means" – all of which can be disastrous when developing technical solutions that require cooperation among communities to develop a technical plan that addresses both current and future needs.

The submarine community, for example, has long held the moniker of "The Silent Service" with independent operations infrequently interspersed with extremely low data rate communications. In the airport that services the Naval Undersea Warfare Center (NUWC) there is a poster that says, "*NUWC, Rhode Island's Best Kept Secret.*" The Navy laboratory that supports the undersea warfare community has historically adopted the cultural makeup of the community it serves.

John Donne wrote in *Devotions upon Emergent Occasions* (1624), “No man is an Illand, intire of it selfe; every man is a peece of the Continent, a part of the maine…”. Likewise, no part of a system is independent of the other parts; nor, in many cases, is a system independent of other systems.

2.3.2 Where Is the Navy Today?

In order to establish the context for HWIL simulations within any organizational framework – be it Department of Navy or the Naval Undersea Warfare Center – we must first consider the advantages of HWIL over other kinds of simulations, and, second, identify and address the problem space where the prudent use of HWIL simulations are particularly advantageous. Verification, validation, and accreditation (VV&A) attempts to establish sufficiency in the applicability of a *particular* tool (simulation) to a *particular* problem for a *particular* user.

For the purpose of this paper and to understand our approach to the verification, validation, and, ultimately, accreditation of hardware-in-the-loop simulation systems, we must ask ourselves three questions:

1) What, in the broadest possible sense, is hardware-in-the-loop simulation?
2) What are the defining characteristics of the hardware-in-the-loop (vs. digital) simulations?
3) What are the specific applications for hardware-in-the-loop simulations?

What is a hardware-in-the-loop simulation? First and obviously, a hardware-in-the-loop (HWIL) simulation is a type of simulation that contains all or part of an operational system. This is in contrast to a purely digital simulation that contains virtual representations of all the systems in the simulated world. Second, by “in the loop” we mean that the hardware is not simply being stimulated in an “open loop” fashion but rather it is reacting to the simulated world around it, and consequently, altering the simulated world in a “closed loop” fashion. Operational hardware can be purely hardware or hardware and embedded software. The simulated world in which the operational hardware is immersed contains representations of the natural/physical environment and of the other systems in the operational space.

The WAF at NUWC is a HWIL simulator for torpedoes, undersea acoustic countermeasures, and eventually, unmanned undersea vehicles. The WAF provides the Fleet with torpedo-centered facilities that enable modeling and hardware based performance assessment of current and projected undersea weapon systems, tactics, scenarios, countermeasures, targets, and environments. Its architecture is illustrated in ***Figure 2.3-1***. The facility was originally developed to support the Navy's heavyweight torpedo, the Mk48 ADCAP. Demonstrated success led to the inclusion of the lightweight torpedoes (the Mk46, the Mk50, and the Mk54), platform defensive and countermeasure programs, and exploitation programs in the supported suite. The WAF computers create a total simulated environment in which selected components of weapon hardware are exercised in all aspects of torpedo engagement against both submarines (ASW) and surface ships (ASUW).

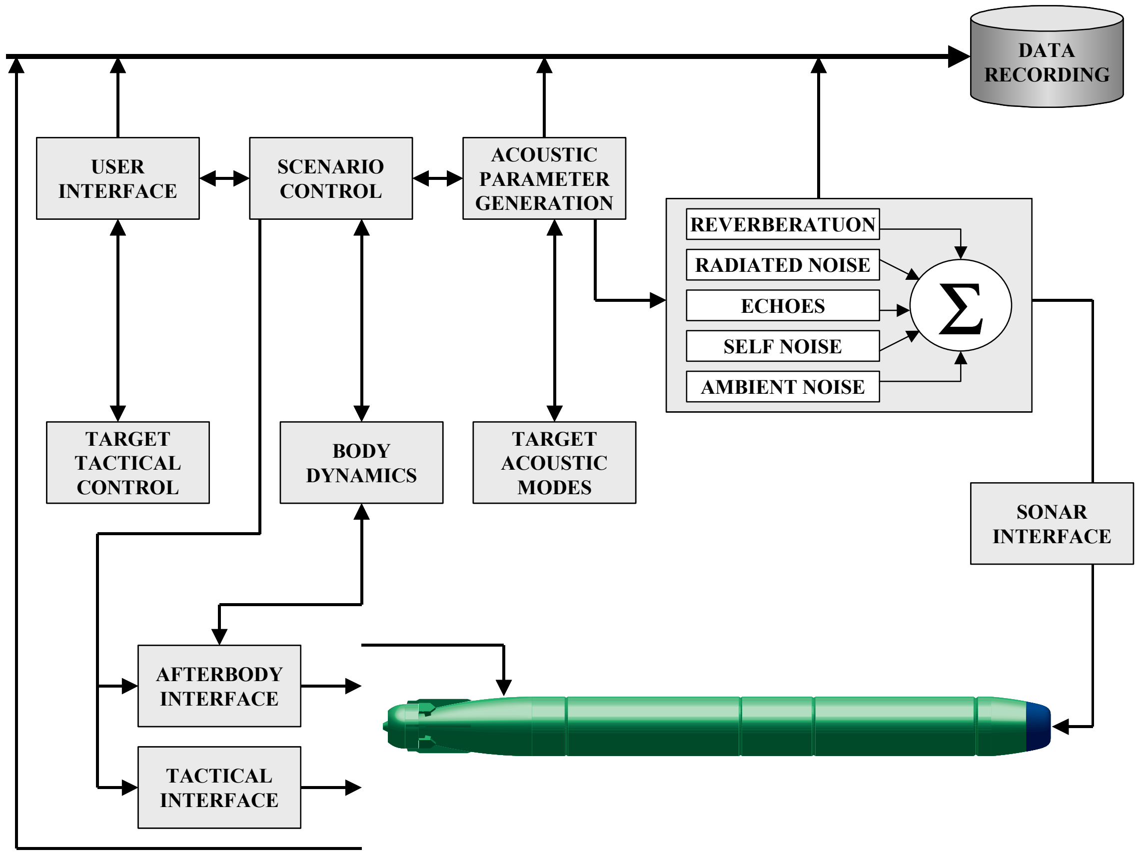

Figure 2.3-1. WAF Architecture.

The Synthetic Environment Tactical Integration (SETI) program connects the hardware-in-the-loop torpedo simulation capabilities in the WAF with fleet submarines operating at depth and speed on range at the Atlantic Undersea Test and Evaluation Center (AUTEC) as shown in ***Figure 2.3-2***. SETI integrates the WAF with the tactical fire control equipment on-board the submarine using underwater tracking systems, underwater acoustic telemetry and wide area network technologies. Through SETI, a submarine crew can engage a live target on the range and conduct an attack using a hardware-in-the-loop Mk48 ADCAP torpedo located in the WAF. Both the firing and target submarines then can see the simulated torpedo in real time while submerged, thus allowing for weapons wire guidance and target evasion. With the addition of planned connectivity enhancements, SETI will provide simulated targets, countermeasures and ocean environments.

Our definition of HWIL includes Installed Systems Test Facilities (ISTF) such as the Naval Air Warfare Center's Air Combat Engineering Test and Evaluation Facility (ACETEF). The primary mission of ACETEF is to reduce program risk for NAVAIR systems throughout the acquisition life cycle. ACETEF's primary purpose is to test installed aircraft systems in an integrated multi-spectral warfare environment using state-of-the-art simulation and stimulation technology. Aircraft platforms, typically placed in an anechoic chamber, are made to behave as if they are in a real operational environment through a combination of digital simulations and stimulation by computer-controlled

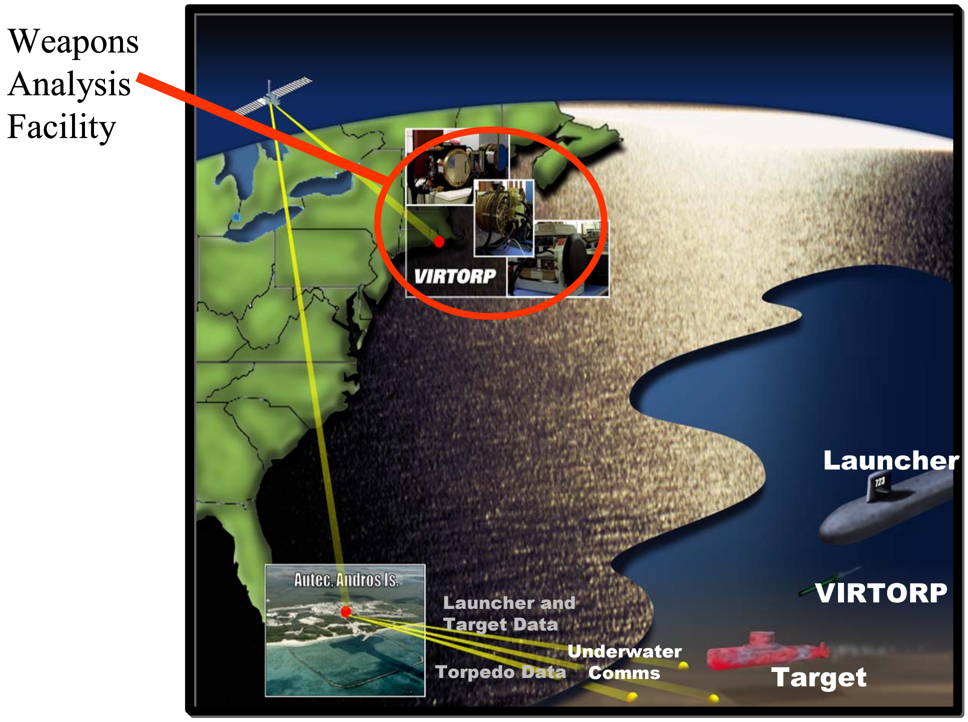

Figure 2.3-2. The Synthetic Environment Tactical Integration (SETI) Program.

environment generators. The ACETEF has several laboratories providing signal generation, man-in-the-loop cockpits, high-performance computing (HPC), and warfare environment. These laboratories can work autonomously or collectively to provide varying levels of test and analysis capabilities.

What are the defining characteristics of the hardware-in-the-loop simulations? The defining characteristic of the HWIL simulation is that it contains all or part of a piece of operational hardware. But that is only the tip of the iceberg. Hardware in the simulated environmental loop leads to some very important secondary, or implied, considerations. First, typical operational systems, at least those of any substantive degree of complexity, understand time as constant, monotonically increasing. Second, the interfaces to the operational system are defined, not by the simulation engineer, but by the engineer responsible for the operational system. Third, the operational hardware is a sample of one in the inventory space. While some HWIL implementations may make the swapping of operational hardware an easy matter, the sample size is still relatively small when compared with parameterizable digital simulation. And finally, the hardware "is what it is;" specifically, we need not concern ourselves too deeply- apart from understanding the pedigree of the specific unit under test and its operational condition- with validity of the operational hardware itself.

a) Description of Objective Systems.

A highly generalized and simplistic view of the HWIL simulation is provided in ***Figure 2.3-3***. The unit under test, that is the operational hardware in the loop, is connected to the simulated environment by a collection of specific interfaces. These

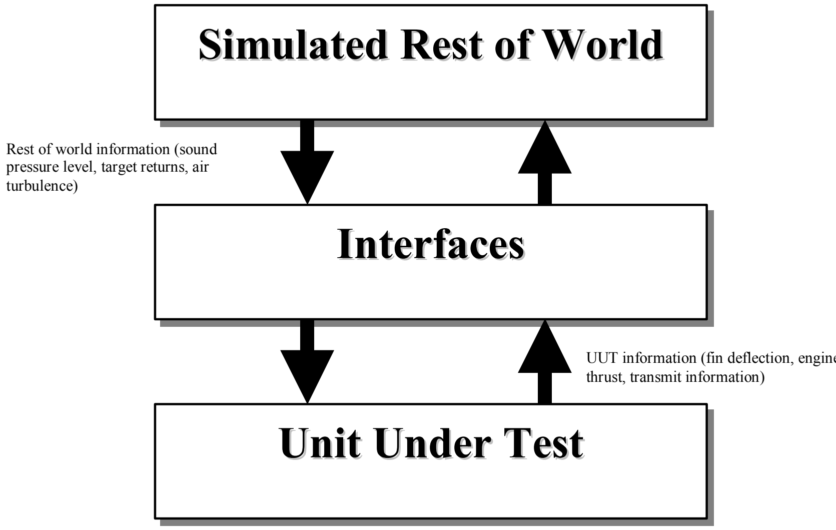

Figure 2.3-3. Generalized HWIL VV&A Process.

interfaces are conduits through which "world" information (i.e. information about the present condition of both the natural and combat environment) moves from the simulated world to the unit-under-test (UUT), and UUT information (i.e. fin deflection, transmission, detonation) moves from the operational hardware to the simulated world. In the case of Installed System Test Facilities (ISTFs), some of the interfaces between the simulated world and the unit under test may be the same as in the real world (i.e. infrared (IR) radiation transits through the air and impacts IR sensors in the operational system). While admittedly simplistic, ***Figure 2.3-3*** helps us focus on those issues specific to HWIL VV&A. If the unit under test "is what it is" there can be little issue over its design accuracy. What remains are the interfaces between the unit under test and the simulated world and the simulated world. And finally we must consider the HWIL as a complete system.

Applications well suited for HWIL are those that require either a high degree of confidence in the implementation of the target operational system, or where, for training and testing purposes, the human-machine-interface matches, as closely as possible, the operational system. Some specific applications of HWIL simulations are integrated systems testing, developmental and operational testing, training, foreign military exploitation, etc. These, being very rigorous applications, typically require a higher degree of confidence than other applications and are all but impossible to successfully replicate in a totally virtual environment.

b) Fundamental Strategies For Business Operations.

FUNDING. Budgets are shrinking and we are all expected to do more with less. VV&A is no exception and it may in fact be the poster child. Being results oriented, we tend to put an emphasis on delivering a simulation system and verification and validation can, unfortunately, become a secondary consideration. We all need to strive to 1) change that culture which relegates V&V to a second order fiscal decision, and 2) as a technical community find ways to weave good V&V practices into our design processes. As a minimum we must understand cost of V&V, but cost estimates for specific V&V processes instantiations are difficult to predict. Parametric cost tools (e.g. Price Systems, Gallorath) may have applicability here. Specific V&V cost tools are available. One such tool, VV&A Cost Estimating Tool (VVA-CET) was developed by DMSO and the Army and provides a good first cut. We hope that continued investment in these kinds of tools is forthcoming and data accumulated through experience can be fed back into the tools.

V&V AS AN INTEGRAL PART OF THE DEVELOPMENT PROCESS. Apart from some of the documentation and personnel requirements, V&V, when done right and early, does not require a developing activity to do substantially more work than they are already doing. Developers build their simulations from a set of requirements and specification. Testing at the unit and system level is done routinely. Simply leveraging these activities and others like them (insisting, for example, that each engineer maintain an engineering notebook where requirements' implementation and other proximate design descriptions are documented) can go a long way toward providing a solid V&V foundation. Hardware engineers will, as a matter of course, document interfaces in interface drawings. These should all become part of the V&V pedigree.

SIMULATION CONTROL PANEL. Early and continued involvement of the user community is absolutely essential. Where possible, a Simulation Control Panel (SCP) should be chartered and tasked from the highest sensible level in the reporting chain. The SCP is responsible for watching the development process and overseeing the ultimate verification, validation, and accreditation of the simulation system. Membership on the SCP should include representatives of the design team, the V&V team, the accreditation team, the sponsor(s), and other interested parties. Requirements, specifications, model selection, etc. should all be vetted through the SCP. Direction for V&V should be established by the SCP. The SCP should review and put their imprimatur on the V&V plan. This ensures that all interested parties are "on the same sheet of music." During the V&V process, the SCP should be periodically briefed on progress. In situ rudder orders should be minimal if all parties agreed on the strategy up front. The SCP should review and endorse the final results of the formal V&V process.

CONFIGURATION CONTROL BOARD. Throughout the development process, the Configuration Control Board (CCB) should be hard at work monitoring software product development. In addition to software configuration control, the CCB of an HWIL must have cognizance over the hardware configuration as well.

c) Techniques & Technologies.

Figure 2.3-4, below, outlines the Navy's VV&A recommended process as spelled out in both SECNAVINST 5200.40 and the Navy's VV&A Implementation Handbook. The following discussion relates to HWIL specific questions re: VV&A. There are many other things that need to be addressed from the general M&S point of view but, in most cases, they are outside the scope of this paper. The issues associated with each step as they relate to HWIL are contained in the following paragraphs.

REQUIREMENTS DEFINITION. The process of defining requirements for an HWIL simulation is not very different than the process followed to define requirements for any other simulation system. First, customer and user needs are evaluated in light of

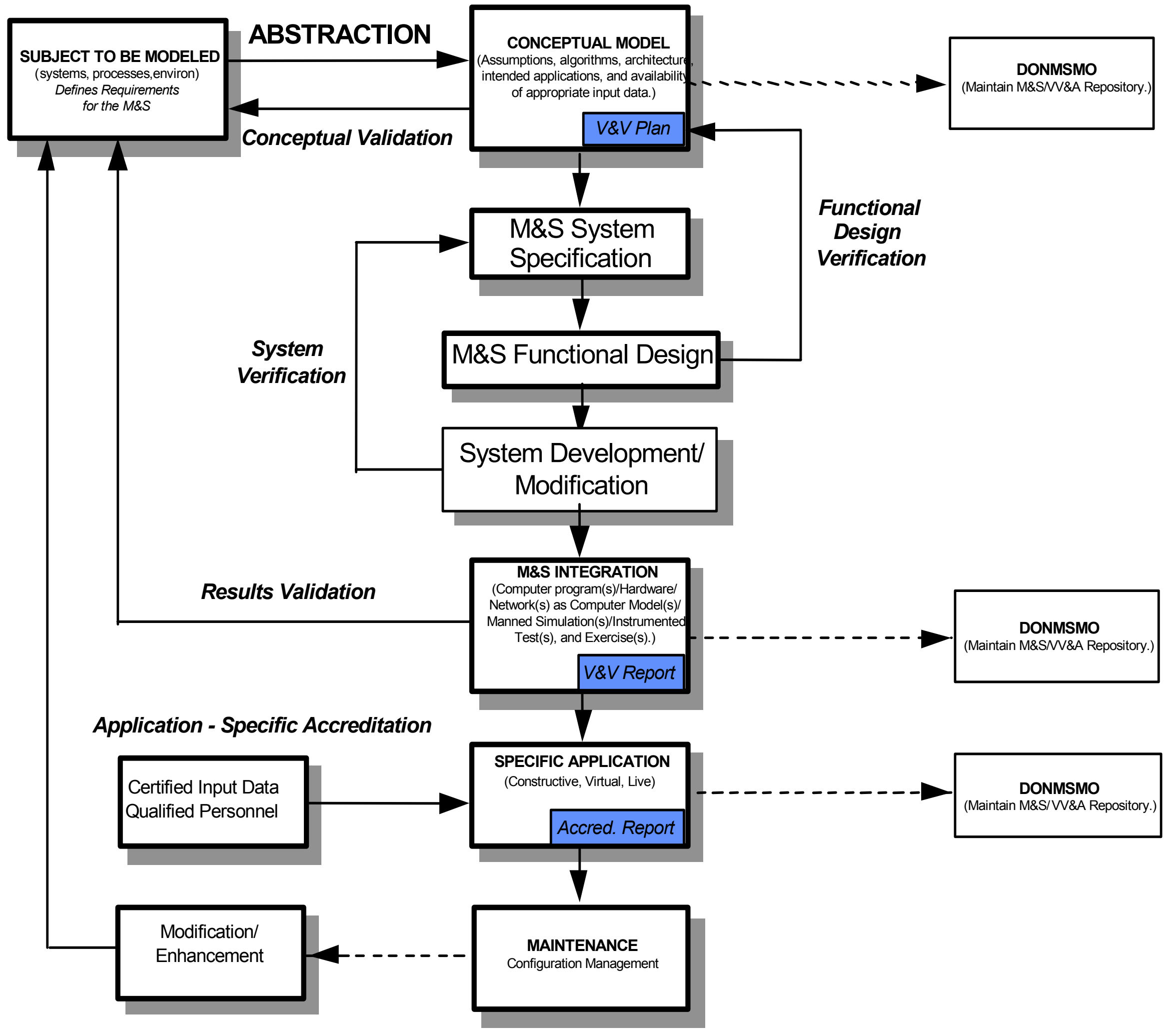

Figure 2.3-4. Navy's Recommended Simulation VV&A Process.

available modeling science and available dollars, and then the needs are translated into requirements.

Introduction of real operational hardware into a simulation environment introduces specific requirements (over and above those already established) that can be characterized as either Interface Requirements or Timing Requirements. Interface Requirements are naturally tied to the specific piece of hardware in question and may be so specific that they relate to particular versions of hardware and operational software. Weapon interface requirements, particularly as they relate to signal injection strategies, will drive, to a point, the models used in the simulation world. Timing requirements, on the other hand, have a profound influence on the selection of models used in the simulation world. HWIL simulations are, by and large, tied to real-time operations. But when dealing with operational hardware with very specific timing needs (i.e., frame rates), attention must be paid to the definition of real-time.

Consider ***Figure 2.3-5***. Two simulations, represented by "Simulation A" and "Simulation B" are used to interface to hardware that expects something like that

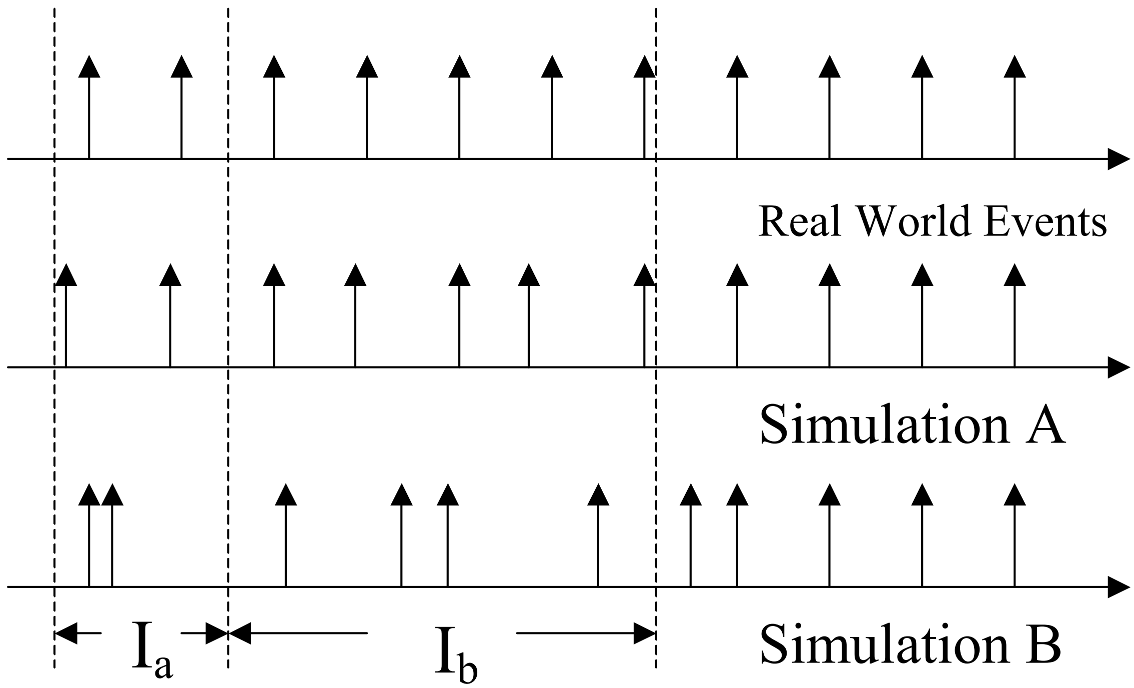

Figure 2.3-5. Timing and Synchronization of HWIL Simulations.

depicted in the timeline at the top. Over large intervals of time, both Simulation A and Simulation B appear to meet the hardware's requirements. But for shorter integration intervals, Simulation B will, in some cases (I_a), be ahead of the hardware (adding delays may be sufficient to solve this problem) and, in other cases (I_b), events happen late and result in invalid behavior. Some hardware platforms will flag this as a failure and stop execution. Others may not be so smart and actually continue running.

Timing requirements can, secondarily, drive model selection. Navy operational domains necessitate a heavy emphasis on accurate modeling of the natural environment. Near water surface interactions have a profound effect on IR/RF signal propagation. Shipboard over the horizon radar requires accurate modeling of the refractive elements of the atmosphere. The undersea acoustic propagation environment represents an especially difficult case.

Torpedoes, in particular, use acoustic radiation to detect, classify, localize, and home on its target. Weapons systems within the WAF are typically stimulated with element level, time domain acoustic data. This acoustic data is a summation of target returns (refracted/reflected in the medium), volume and boundary (i.e. surface, bottom) reverberation, ambient noise, torpedo self-noise, etc. Reverberation is, far and away, the most computationally intensive modeling task. A heavy computational load juxtaposed against a real-time HWIL requirement severely limited both our choice of reverberation algorithm and our implementation strategy.

CONCEPTUAL MODEL VALIDATION. For U.S. systems, the process for the determination and subsequent verification that the requirements are met is straightforward. Consultation with system designers and the foundation documents (requirements, specifications, etc) related to the system in question are invaluable. Foreign systems, on the other hand, are a different story. In most cases, access to the designers is absolutely impossible (understandable) and access to documentation can be problematic. In this case, access to the exploitation team is critical. And even then, "face validation" may be the best we can hope for.

During this phase, a VV&A plan should be developed that takes into account all of the requirements associated with designing, building, and testing a HWIL simulation system. Specifically, the plan should address the following (as it relates specifically to HWIL):

- Assumptions about the interface design. Include information about specific hardware versions and applicability to other versions of both operational hardware and software.
- How the models used in the "simulation world" fit the hardware application. For example, torpedoes use acoustic sensors to detect, localize, and classify their targets. These sensors have specific requirements for signal quality usually based on the signal processing done in the operational hardware. If the weapon system is expecting data of a particular resolution, then the model should produce data of at least that resolution. If producing data at the required resolution is impossible, then an explanation of the lack of resolution on hardware performance should be documented.
- Where exploitation hardware is used, rigorous verification and validation, in concert with those performing the exploitation, some consideration to the verification and validation of the interfaces needs to be addressed.
- Timing requirements should be documented and a statement of how both model and simulation computer selection meets these requirements be included. In many cases, FLOP requirements can be counted and mapped to the available compute hardware to clearly demonstrate a continuously realizable schedule (perhaps an application of the rate monotonic scheduling algorithm can show this correlation).
- For Installed System Test Facilities (ISTFs), document the impact of the local environment (e.g. that in the anechoic chamber) to the signal as it's received by the hardware. Presumably, RF radiation traveling the short distances in the anechoic chamber at Patuxent River will behave, to some degree, differently than those same signals traveling through the air over some threat nation's capitol.

As stated earlier, the Navy puts a high priority on the accurate modeling of the synthetic natural environment. The Maritime Environment Data Server (MARVEDS) project (sponsored by NAVMSMO) has developed what they call the Environmental Concept Model, or ECM. The ECM provides a procedural framework to bring users, and their use cases, together with model providers/developers. ECM sits between those two groups to match requirements to capabilities. This is an important step in the VV&A process as VV&A is very application specific.

SPECIFICATION, DESIGN, AND DEVELOPMENT. During these phases, the V&V and accreditation teams should be reviewing the documents produced by the simulation engineers as well as the implementation strategies followed by the development team.

Interface documents should be reviewed to ensure that all necessary signals to and from the unit under test are accounted for. Consultation and review with the weapons designers (or exploitation agency) is extraordinarily beneficial. These interchanges should be documented and included in the V&V documentation list.

HWIL simulations are required to handle timely servicing of many complex events throughout the execution cycle. Unlike purely digital simulations where execution flow can be thoroughly monitored and controlled, the HWIL simulation is at the mercy of the unit under test. One interesting challenge for the HWIL V&V team is to understand whether or not the HWIL "rest of world" simulation and the interfaces will always meet the real time needs of the unit under test.

Rate Monotonic Analysis[3,4,5] (RMA) is a useful tool for gaining insight into an algorithm's timing behavior. Today's real-time operating systems (VxWorks, pSOS, Real-time POSIX compliant UNIX) provide tight control over execution threads and, for reasonably closed formed solutions (e.g. RF radiation traveling from source to target to receiver), worse case computational loading can be readily determined. Application of RMA should reveal whether or not real-time schedules are realizable and if not ascertain the ultimate impact to simulation weapon performance.

M&S INTEGRATION. During the integration phase, unit and system testing should contribute to results validation. Instrumentation of the simulation at this point is critical. For example, oscilloscope traces can be instrumental in verifying that signals are getting to their intended target in an accurate and timely fashion.

d) Maturity.

The Navy's V&V process has evolved and is well-defined by several layers of instructions. NUWC's HWIL simulations operate under DoDINST 5000.61, DoD Modeling and Simulation (M&S) Verification, Validation, and Accreditation (VV&A), and SECNAVINST 5200.40, Verification, Validation, and Accreditation (VV&A) of Models and Simulations. For OT&E, NUWC also follows COMOPTEVFORINST 5000.1, Modeling and Simulation in Operational Testing. ***Figure 2.3-6*** overlays the integration process used in the WAF on the Navy's Recommended Simulation VV&A Process.

Assisting in the V&V process is the Navy VV&A Recommended Practices Implementation Handbook that is designed to provide amplification and practical guidance for those responsible for implementing the SECNAVINST. A separate document contains templates for planning, reporting, and documenting a VV&A product and a detailed example implementing the DON VV&A process.

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4. Serlin, O., "Scheduling of Time Critical Processes," 925-932. *Proceedings of the Spring Joint Computer Conference*. Atlantic City, NJ, May 16-18, 1972. Montvale, NJ: American Federation of Information Processing Societies, 1972.
5 Sha, Klein, and Goodenough, J., "Rate Monotonic Analysis for Real-Time Systems," 129-155. *Foundations of Real-Time Computing: Scheduling and Resource Management*. Boston, MA: Kluwer Academic Publishers, 1991.

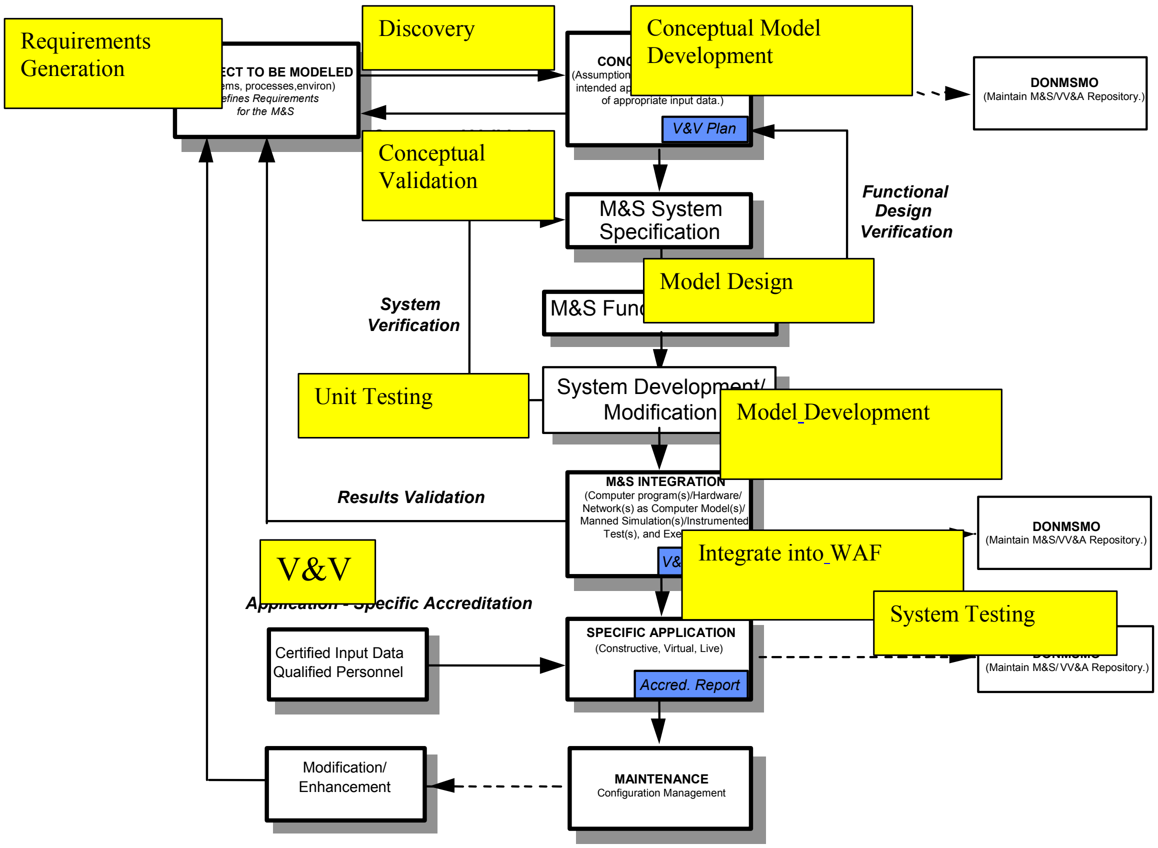

Figure 2.3-6. WAF V&V and HWIL Integration Process.

e) Measures of Success.

Measures of success can be categorized into two different groups. First, "Did the V&V process add value to the development process?" Second, "Did the V&V process provide a rigorous enough basis upon which to make an accreditation decision" and, as a corollary, "Was the simulation used for the intended purpose?"

VALUE ADDED. Verification and validation for its own sake has little defense. Certainly, V&V may (sic) be the deciding factor in using (or not using) a particular simulation. Unfortunately, V&V is not yet an integral part of the language of program offices. Many are just not well versed in the requirements for V&V and, therefore, don't ask the right kinds of questions. Often, use decisions are based on experience with a legacy model, on the perceived integrity and technical capability of the developer of a simulation system, or some other less noble reason. In reality, if this cultural myopia is ever to be overcome, V&V must add value to the development process. If we think of V&V simply as a robust testing process, it's not hard to change our thinking from V&V is something I must do to V&V is something I should do.

V&V, as defined by so many policy and guidance documents, provides simulation developers with a framework for detailed testing of a simulation system. If V&V is an integral part of the development process, then it can be instrumental in illuminating failures (and successes) in the implementation of a particular simulation system. Furthermore, those findings are there for all to see and understand and form what amounts to the corporate memory for the simulation. Documenting assumptions, design decisions, engineering implementations and the intentions behind them can be an invaluable resource for new developers, customers, and sponsors. In a documentation challenged environment, unnecessary rework and rehashing old questions is sure to be a part of daily life. In a documentation rich environment, this unnecessary expenditure of energy can be greatly minimized. For example, by reviewing the intent behind the selection of a specific environmental model, a design team can often avoid wasting time going over the same kind of questions again. A review of the old models assumptions can often direct future investment and can form the basis of selection criteria for emerging algorithms. Because the documentation is, in a sense, in the public eye, it forces us to honestly consider the applicability of a simulation system to a particular problem space. This honest selling of simulation capability can only strengthen confidence in modeling and simulation in general.

It follows naturally, then, that the V&V process should represent only a marginal cost increase over a development process that does not include V&V. And the definition of the "margin" must be based on the benefits associated with a rigorous test process as described above. If V&V is not an integral part of the development process, it's highly unlikely that V&V will not be intrusive on the development budget. But a focused V&V effort that is intimately tied to the development process should provide benefits that far outweigh the costs. But we can't stop there. Up-front negotiations with the user community are absolutely critical. The negotiations must be documented and signed by all interested parties lest the whole effort suffer from "requirements creep" or worse, wholesale redirection.

THE ACCREDITATION DECISION. V&V should lead directly to an accreditation decision from the ultimate user of the simulator. Positive accreditation decisions should lead directly to use of the simulation for the intended purpose. If accreditation is not followed by use, then unnecessary energy was expended and nobody benefits. Negative accreditation decisions can also be valuable. First, the negative decision provides the simulation proponent insight into where their simulation fell short for a particular application. Second, the accreditation authority can refine their methodology for initially choosing one simulation over another for particular uses. And third, a potential travesty (i.e. using the wrong tool for the right job) has been avoided.

f) Synopsis / Summary.

Table 2.3-2 lists M&S VV&A reports currently on file with the Navy Modeling and Simulation Management Office. This list clearly shows that it is possible to V&V HWIL systems and that they can be used successfully to make acquisition, test, and mission decisions.

Table 2.3-2. Navy HWIL VV&A Documentation.

Program	Document Title
AAAV	Accreditation of the TIGER Simulation for Calculation of Mean Time Between Operational Mission Failure (MTBOMF)
CEC OT-IIA3	Verification and Validation Assessment Report for the Cooperative Engagement Capability Hardware-In-The-Loop Systems for OT-IIA3
CEC OT-IIA4	Accreditation of the Cooperative Engagement Capability (CEC) Hardware in the Loop (HWIL) Simulation in Support of CEC AN/USG-2 System for OT-IIA4 Operational Evaluation (OPEVAL)

Table 2.3-2. Navy HWIL VV&A Documentation.

Program	Document Title
CEC OT-IIA4	Verification and Validation (V&V) Report for the Cooperative Engagement Capability Eastville Tower, Eastville, VA Hardware-in-the-Loop System for OT-IIA4
CEC OT-IIA4	Verification and Validation (V&V) Report for the Cooperative Engagement Capability Surface Combat Systems Center, Wallops Island, VA Hardware-in-the-Loop System for OT-IIA4
CEC OT-IIA4	Verification and Validation Report for the Cooperative Engagement Capability NP-3D Airborne Research Platform Hardware-in-the-Loop System for OT-IIA4
CEC OT-IIA4	Verification and Validation (V&V) Report for the Cooperative Engagement Capability Multi-Function Land Based Test Site Dam Neck, VA Hardware-in-the-Loop System for OT-IIA4
FA-18E/F	Accreditation of Capability of the FA-18E/F Manned Air Combat Simulator 3 (MACS 3) and FA-18C/D MACS 2 Simulator to Support Operational Test and Evaluation of the FA-18E/F
GCCS-M	Accreditation of the Land-Based Test Facility (LBTF) for the Mobile Operations Control Center (MOCC) Component for the Global Command and Control System-Maritime (GCCS-M) Software Qualification Test (SQT) / Follow-On Operational Test and Evaluation (FOT&E) (OT-IID6)
GCCS-M	Accreditation Assessment Report for GCCS-M Mobile Operations Control Center Land-Based Test Facility to Support GCCS-M OT-IID6
MJU-52/B BOL/IR	Accreditation of Capability of the Naval Surface Warfare Crane Seeker Test Van and Airborne Turret Infrared Measurement System Pod to Support Operational Test and Evaluation of the MJU-52/B (BOL-IR) Infrared Countermeasure
Navy Theater Ballistic Missile Defense (NTBMD)	Modeling and Simulation Requirements [Navy Area Theater Ballistic Missile Defense (Navy Area TBMD) System]
TOMAHAWK	Final Accreditation of the TOMAHAWK Land Attack Missile (TLAM) Mission Validation System (MVS) / Register Level Simulation (RLS) Version 5.1 to Support Follow-on Operational Test and Evaluation of the TOMAHAWK Mission Planning Center (TMPC) Version 3.2.
V-22	Accreditation of the Air Combat Environment Test and Evaluation Facility (ACETEF) MV-22 Full Mission Simulator (FMS) to Support Operational Test and Evaluation (OT-IIE) of the V-22
Virginia Class NSSN	Accreditation of NSSN Command and Control Systems Module (CCSM) Off-Site Assembly and Test Site (COATS) for use in NSSN OT-IIB Event
Virginia Class NSSN	Accreditation of SIMII/SSTORM (Scenario Structured Torpedo Requirements Model) to Support the Operational Assessment (OT-IIA2) of the Virginia Class SSN

2.3.3 Where Is The Navy Going?

In the last several years, Navy leadership has recognized the need for a Revolution in Military Affairs (RMA). "*Forward from the Sea*", a visionary document developed by the Chief of Naval Operations (CNO), highlighted the decisive shift from blue water operations to the "brown water" of the littoral following the Cold War. The move to the littoral is not merely a change in location; rather, this shift represents a monumental challenge to our technical and operational personnel to overcome a more complicated physical environment, increased threat capability and density, and heightened vulnerability.

a) Intention and Rationale.

The littoral environment mandates that we can no longer afford to view our Navy as made up of scores of lightly connected assets (i.e. a platform-centric view). The complexity of the Navy's new (littoral) operational environment implies that no *one* platform has either the perfect picture of its immediate operational space or a comprehensive picture of the theater of operation. Led by retired Vice Admiral Arthur Cebrowski, the Navy developed and is, in several arenas, continuing to evolve the "Net Centric Warfare" concept. Like the tank in World War I and the aircraft carrier in World War II, high-speed communications (data, video, voice) and platform connectivity will revolutionize the way we fight wars by sharing an enhanced and common operational picture among all of the platforms in the operational theater. This RMA, in turn, will lead to a vast improvement in speed of command by vesting all of the platforms with the operational picture and pushing command authority to lower levels in the command chain.

b) How We Are Going To Get There?

In this new paradigm, both acquisition and operations will view the platform, the battlegroup, the fleet and the navy as a highly interconnected, and by extension interdependent, collection of sensors, shooters, and weapons. Programs and initiatives such as Navy's Distributed Engineering Plant, Cooperative Engagement Capability, and ForceNET, along with the associated organizational shifts in both the acquisition and operational communities, indicate that the move to net-centricity is well underway.

c) Expectations?

The changes to the scope of Navy's mission will have profound effects on Navy's operational, acquisition, and R&D budgets. It should not be a revelation to anyone with even moderate familiarity with the DoD that our nation's military is being asked to do more with less. The current administration has indicated that it will increase the DoD budget in the ensuing years, but the pundits are still debating whether or not those increases will be enough to sustain capabilities to support current mission requirements. Transformation to net-centricity will have its cost. While current leadership does seem willing to make deep vertical cuts in programs (e.g. Army's Crusader program) when necessary, estimates are that a 10-20% increase in investment will be necessary.

d) Why do we want to get there?

Many within the DoD acknowledge the need for transformation; it clearly means different things to different people. For some, it is synonymous with modernization and focused on material acquisition. Others more appropriately see transformation going beyond modernization to embrace innovation and fundamental changes in our theory of war. Specifically, Network Centric Warfare (NCW) is such an innovation. Last year, in the conclusions to the report to the Congress, the Department of Defense said that NCW should be the cornerstone of DoD's strategic plan for the transformation of forces.

e) What Do We Gain From Getting There?

With the forthcoming RMA, Navy will shift from a platform-centric view to a force-centric view of the world. This will result in a heavy emphasis on architectures, communication, and platform interoperability.

2.3.4 What Is The Risk?

HWIL simulations are necessarily platform-centric in their design and, when considered individually, at best provide a piece-wise understanding of the "condition" of the battlegroup. In some cases, HWIL simulations can be married to much broader combat environment simulations such as the ACETEF and the Joint Interoperable Mission Model (JIMM). This still only provides a detailed look at the aircraft that happens to be sitting in the anechoic chamber.

In the early 1980's, the Defense Advanced Research Projects Agency (DARPA) sponsored a program (SIMNET) to link geographically distributed trainers. Out of that work, Distributed Interactive Simulation (DIS) protocols emerged. In the early-90's, the Defense Modeling and Simulation Office (DMSO) began development of the High Level Architecture (HLA). The HLA, now IEEE standard 1516, provides for simulation-to-simulation interoperability.

The Naval Air Warfare Center (NAWC) has used the HLA to connect live operational assets with HWIL simulators at Point Mugu in what is called the Virtual Missile Range (VMR). NUWC linked the WAF with an operational submarine (at speed and depth) enabling it to fire virtual torpedoes. The HLA is the enabler for joining geographically distributed live, virtual, and constructive forces together into a virtual environment.

Recall the typical use cases for HWIL simulations: integrated systems testing, developmental and operational testing, training, foreign military exploitation, etc. These are the same kind of functionality that NCW will require. NCW will require distributed simulation testbeds for testing architectural concepts, for exploring communications paradigms, and for evolving the military culture through demonstration and training.

The challenges to the V&V team in the "new world order" are many and varied. Below is simply a stab at probably some of the most important. Some of these, no doubt, are not limited to HWIL. However, expectations surrounding HWIL are generally high (i.e. it's the real hardware) and therefore HWIL V&V teams need to be extra sensitive to these challenges lest expectations run higher than capacity.

Cost: The cost of validating a distributed testbed will be difficult to manage. Surely, the testbed engineer should be able to count on a rigorous V&V process for each of the constituent elements of the test bed.

Fair fight: Without standard "fidelity" requirements, ensuring that one platform's simulation does not have an accidental advantage over another (i.e. one simulator can afford trees the other can not).

Latency: The real-time nature of the HWIL mandates that incoming data be received in a timely fashion. When simulators are distributed over large geographical ranges using non-deterministic networks, ensuring the consistent timely arrival of data is difficult.

Data recording: Where's the testbed validator going to go for a complete picture of the simulated battlespace?

Distributed Clocks: Who owns time?

2.4 US Air Force Electronic Warfare Evaluation Simulator Test Facility

2.4.1 Context

The preceding sections predominantly focused on HWIL and distributed simulations that are used to evaluate blue weapon systems. In contrast, this section will address HWIL simulations used to assess effectiveness of countermeasures and techniques used against threat weapons, particularly missiles. Additionally, this section is very specific to the particular challenges faced by the US Air Force Electronic Warfare Evaluation Simulator (AFEWES) Test Facility. Many of the issues addressed and the approach to resolving these issues are generalizable, but no attempt to extend an approach to another venue or problem is made. For these reasons slightly more space will be dedicated to a more detailed description of the AFEWES mission and HWIL applications.

The AFEWES HITL (the Air Force tends to use the acronym HITL for hardware in the loop as opposed to HWIL) test facility is located in Ft Worth, TX and reports to the 412th Test Wing/Electronic Warfare Directorate, part of the Air Force Flight Test Center. The AFEWES mission is to perform effectiveness evaluations of US and allied electronic warfare (EW) systems and techniques against threat missiles. AFEWES develops and operates high-fidelity HITL radio-frequency (RF) and infrared (IR) simulations of Surface-to-Air Missiles (SAMs) and Air-to-Air Missiles (AAMs) for 1-v-1 countermeasure effectiveness assessments. AFEWES also operates a very dense RF environment generator to produce 1-v-many engagements and to evaluate electronic warfare receiver performance.

It is easiest to understand what AFEWES does if we consider RF SAMs and infrared threat missiles separately.

2.4.1.1 AFEWES RF Simulations

AFEWES RF testing is used to evaluate different types of electronic warfare equipment and techniques including: onboard RF jammers, towed RF decoys, electronic warfare receivers, self-protect chaff, integrated EW receivers and countermeasures, and aircraft maneuvers. Testing is accomplished at real-time, actual frequency/wavelength in a highly instrumented, real-time environment supporting fully dynamic engagements. A primary result of AFEWES simulations is the determination of vector missile miss distance. Miss distance is essential to understanding and assessing EW system effectiveness and aircraft survivability. Flight characteristics of each AFEWES threat missile simulation are represented with a 6 degree-of-freedom (6-DOF) real-time digital fly-out model developed in close coordination with US intelligence agencies.

AFEWES conducts three types of RF EW system evaluations:

- Open-Loop T&E -- one-way path from threat simulation to EC System used for receiver/processor testing.
- Closed-Loop T&E -- two-way path from threat to EW System and EW system to threat used for defensive countermeasures testing.

- Combined Open & Closed-Loop T&E -- individual high-fidelity threats are embedded in complex, distributed RF laydowns to evaluate dense environment EW system effectiveness.

For open-loop RF evaluations, AFEWES offers a versatile, realistic dense RF environment. Testing of RF/millimeter wave (MMW) receivers, radar warning receivers, and the receiver processors of ECM systems, is accomplished using the Multiple Emitter Generator (MEG). The MEG can generate realistically dense, theater-specific emitter laydowns with a one-half second scenario update rate. A vast array of scenario instrumentation options is available. Seventy-three (73) dedicated instantaneous sources/emitters are provided with up to 20 complex waveform (pulse Doppler) sources. Multiplexing expands this capability to 217 emitters of hostile, neutral, and friendly signals. RF coverage is available from 0.5 to 18.0 GHz, 30 to 40 GHz, and 90 to 100 GHz. National Imagery and Mapping Agency-based terrain masking effects can also be included.

AFEWES RF closed-loop threat simulations use an iterative, real-time solution of the radar range equation based on the aircraft and missile flight paths. Databases representing the radar cross section (RCS) of the victim aircraft, the transmit and receive antenna pattern characteristics of the System Under Test (SUT), and threat antenna characteristics provide inputs to simulation. Actual EW systems can be placed in a secure shield room and interfaced to the AFEWES threat simulations through RF wave guides. Alternately, the JammEr Techniques Simulator (JETS) is used to generate certain classes of EW waveforms if actual equipment is unavailable or cooperative standoff jamming simulation is required. ***Figure 2.4-1*** portrays the AFEWES closed-loop RF T&E approach.

EW system effectiveness is a function of the battlefield environment. AFEWES offers high fidelity threat simulators imbedded in a dense RF/MMW environment. Some RF ECM systems contain receivers, signal processing, and transmitter systems to:

1) Detect the hostile threat environment,

2) Identify and prioritize detected threat systems,

3) Allocate available jamming resources to the highest priority threats, and

4) Activate defensive countermeasures.

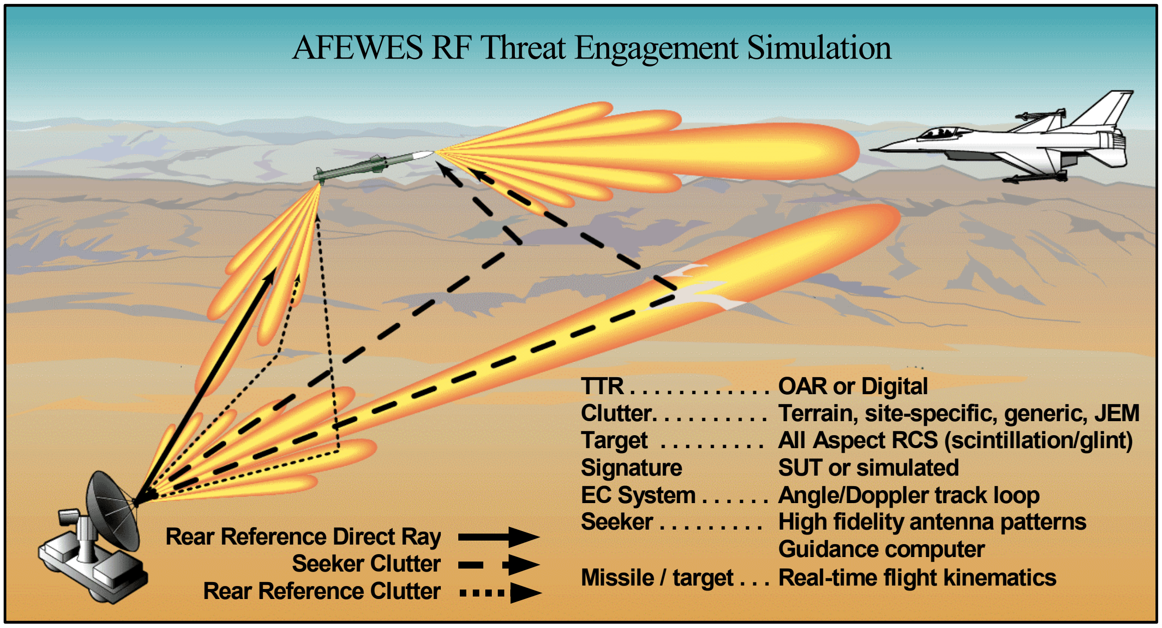

Figure 2.4-1. AFWES Closed-Loop RF T&E Approach.

AFEWES evaluates these systems with imbedded closed-loop high-fidelity RF SAMs in a spatially distributed, real-frequency emitter laydown. Combined open and closed-loop testing enables effectiveness assessment of the overall EW system in a realistically stressing, dense RF environment. Some advanced RF SAMs employ a specialized guidance principle known as Seeker-Aided Ground Guidance (SAGG). The SAGG guidance technique combines semi-active seeker inputs within the tracking loop, which is closed in the ground-based guidance computer, not in the airborne seeker as would be the case in a pure semi-active missile.

To address the effectiveness of EW techniques against these advanced systems, AFEWES and an OAR are pursuing non-real-time interface techniques to integrate simulated radar and missile seeker information to support T&E methods appropriate to evaluate EW techniques against these advanced systems. Test missions will be flown on an OAR. Time correlated data from these OAR flights is then brought into the HITL facility to enable representation of the functions of the radar illuminator, clutter, EW system modes and timing, and target aircraft time-space-position information (TSPI) during the test flight. This information, along with target radar cross section, antenna pattern information, jammer waveforms and timing, as well as other relevant data are convolved to create time-correlated RF energy which is provided to the HITL simulator via RF waveguides. The HITL seeker simulator is allowed to provide real-time signals to the guidance computer, which then gives commands to a real-time digital fly-out of the missile. A graphical representation of this approach appears in ***Figure 2.4-2.***

2.4.1.2 AFEWES IR Simulations

AFEWES infrared (IR) simulations are used to perform optimization and effectiveness testing of conventional and kinematic flares, directed lamp and LASER

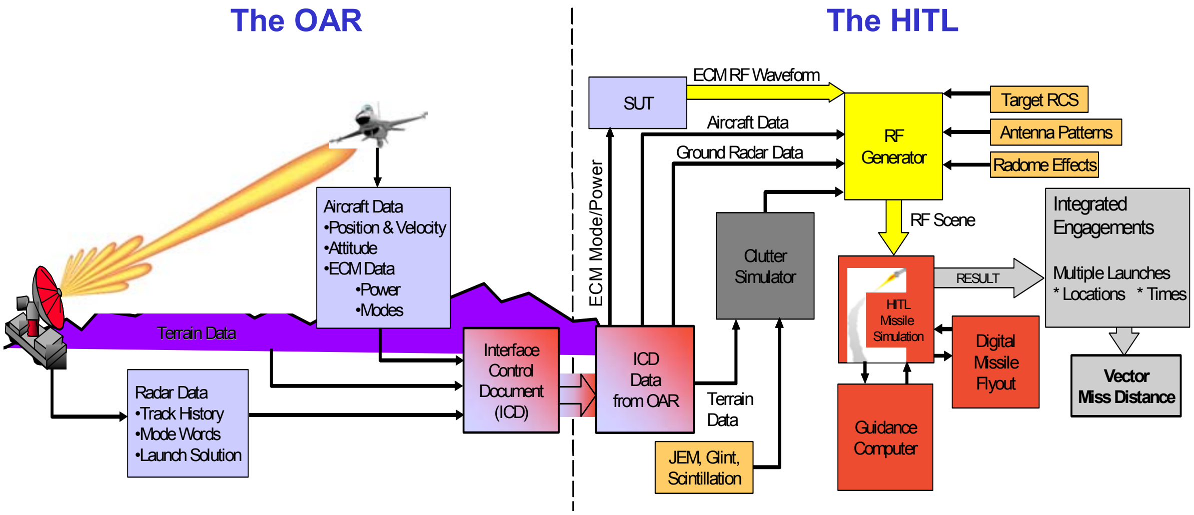

Figure 2.4-2. AFEWES Linkage to Open Air Ranges.

jammers, and combinations of these techniques. The AFEWES IR HITL simulation uses a 9-axis flight motion simulator to provide accurate representation of missile and target motion. An IR foreground presents the radiometric signature of the target aircraft scene including IR countermeasures (flares, lamp or LASER jammers). A modulated LASER may be reflected into the optical path to evaluate the effectiveness of LASER jamming techniques. Multiple LASER transmission heads can be represented on the target aircraft. LASER pointing instability, pointing errors, vibration, and other losses are represented by appropriate dynamic attenuation of the beam. The AFEWES IR Test Facility layout is shown in ***Figure 2.4-3***.

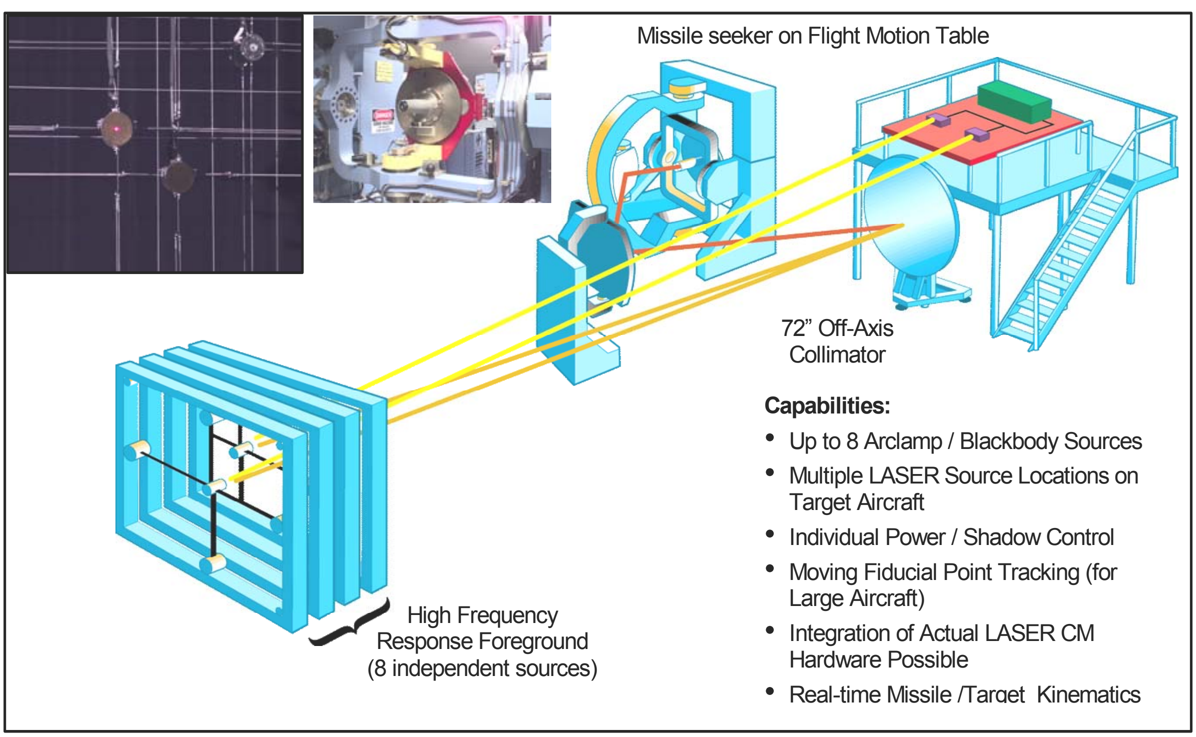

Figure 2.4-3. IR Testing at AFEWES.

2.4.2 *Where Is AFWES Today?*

Verification of the AFEWES RF and IR threat simulation characteristics and performance, as well as validation that they represent a meaningful approximation of the "real world" in the way they are used to assess EW system performance, is critical to acquisition program managers, tactics developers, force planners and ultimately the warfighter. A vigorous, systematic V&V process is ongoing to quantify the fidelity and accuracy of all AFEWES RF and IR threat simulations. Baseline performance characteristics of AFEWES threat simulations is part of the documentation provided to the Government when each HITL missile simulation is accepted. Changes to this baseline caused by upgrades or changes in the hardware or software configuration are maintained by systematic configuration management.

a) Description of Objective Systems.

AFEWES operates high-fidelity HITL simulations of RF semi-active threat SAM systems including seeker-aided-ground-guidance missile systems.

AFEWES operates high-fidelity HITL simulations of IR man-portable air defense systems (MANPADs), IR vehicle-mounted threats and IR air-to-air threat systems.

Please contact the author for further specific information about the simulations available and simulation fidelity of the AFEWES HITL test facility.

b) Fundamental Strategies for Business Operations.

AFEWES has incorporated an integrated process team (IPT) oversight methodology to instill credibility and rigor into our V&V efforts. The reason that we decided on an IPT approach is we had difficulty identifying a single authority that we believed could effectively (and affordably) evaluate our simulation methods as well as the fidelity and pedigree of our input data to determine whether or not our simulation of missile engagements are appropriate and credible. In addition, one could argue, 'who knows more about a simulation than the people who built it and operate it?'

On the other hand, self-V&V seems a little like the fox guarding the hen house as 'what incentive (other than integrity and patriotism) does one have to shine the spotlight on the areas in which one's own simulation falls short?' For us, the solution to this problem was to invite a representative from every appropriate organization within the US Government that we could identify, who had experience and expertise dealing with the threats we simulate, to participate in the development and review of our V&V approach, procedures and specific data collection decisions. The idea is to leverage the capability of others doing related work to ensure that all the essential issues are identified and addressed, in short to keep us honest and to avoid blindspots. We decided to limit the participation to US Government organizations because we really did not have the contractual vehicles or the funding to access industry. As we continue the V&V efforts, consulting or technical support from contractors (who support these other Government entities) may be appropriate and we may fund these specific efforts on a case-by-case basis. In addition, because the data collection, simulator operation, analysis and other technical functions are performed by the AFEWES technical contractor, significant effort and funding are required for each AFEWES V&V activity.

c) Techniques & Technologies.

For our IR V&V efforts we have secured participation from 25 Government organizations. These organizations directly represent varied viewpoints including research laboratory, test facility, operational test agency, test center policy, headquarters policy and plans, intelligence center, program office and operational perspectives from the Army, Navy, Air Force, and Defense Intelligence Agency. We are using a similar approach for our RF simulations and are building IPT membership at the time of this publication. The specific method we use to access the expertise and insight of these individuals is via an iterative process of stating what we intend to do, gaining feedback from the IPT, and incorporating the appropriate feedback. This process can be generally broken into 15 steps as outlined below. Some steps may need to be expanded or may perhaps be eliminated depending on the complexity of the specific V&V task.

1. Form V&V IPT -- identify IPT member organizations and invite participation
2. Articulate general V&V tasks
3. Submit task list to IPT for comment
4. Incorporate IPT comments -- finalize V&V task list
5. Articulate V&V general data collection approach
6. Submit V&V data collection approach to IPT for comment
7. Incorporate IPT comments -- finalize V&V data collection approach
8. Write detailed V&V data collection procedures
9. Submit V&V data collection procedures to IPT for comment
10. Incorporate IPT comments -- finalize V&V data collection procedures
11. Collect V&V data
12. Analyze the data
13. Write the report addressing the findings including limitations
14. Submit the report to the IPT for comment
15. Finalize and publish the report and archive the data

At times, the organization leading the V&V effort may experience difficulty getting active participation from some IPT members (which is perfectly understandable). Members are busy pursuing their own missions, finding time to spend on someone else's problem is difficult, especially when there is sparse funding associated with the task. We have been very fortunate to have received outstanding support from the members of our IPTs to date and are thankful for their dedication and professionalism.

d) Maturity.

(1) Existing AFWES HWIL verification and validation processes

For infrared simulations, we recognized that there were two overarching areas which require V&V effort: first, the portions of any given simulation that are common to other simulations and second, those that are specific to a particular threat system. The first area we call “common elements V&V”, the second is “missile-specific V&V”. Common elements V&V includes characterization of the infrared sources, which represent the target aircraft and countermeasures, flight motion table which enables seeker roll, pitch, and yaw as well as properly presenting the aspect of the target scene, and calibration procedures. Eighty-four separate measurements were identified in the IR common element V&V approach. The approach was vetted with the IPT and detailed data collection procedures finalized. The majority of the data has been collected. The remaining common elements data collection and analysis is funded and scheduled to be finished by the end of CY02.

AFEWES IR common elements V&V is predominantly verification (validation is primarily addressed under missile specific V&V). The common elements effort delivers a baseline of the performance characteristics, response functions and sensitivity of the hardware and software that represent missile and target motion, target and countermeasures signature and waveform, radiometric attenuation due to the atmospheric effects and other causes, and the guidance loop apart from the missile seeker. AFEWES follows a similar approach for IR validation. For each threat missile simulated, we follow the 15-step process identified earlier to develop, refine, and gain feedback on the tasks, approach and procedures for addressing simulation validity from the appropriate IPT of subject matter experts. We initiated planning for the first IR missile-specific V&V effort in FY02. The IPT has been formed and the general task listing distributed for comment. We expect to fund and complete this effort in FY03. We anticipate completing one to three missiles per year until all the IR threats have been subjected to this rigorous evaluation.

AFEWES RF high-fidelity semi-active SAM representations are implemented in three simulation complexes. Each complex utilizes a common system architecture specifically tailored to the appropriate missile requirements. To verify RF SAM simulator capability, AFEWES again uses the IPT concept to design and refine a common set of test procedures to document detailed simulator performance. These procedures are then tailored for the simulation-complex unique functions and missile-specific operational characteristics to gain and document understanding of simulation capabilities and limitations for each threat system represented. Each simulation system design consists of a master control, missile fly-out model (FOM), RF generator, seeker and instrumentation. The master control function includes the real-time scenario, run-time control, data collection and monitoring. The FOM simulates the missile airframe, thruster, aerodynamic characteristics, autopilot and missile antenna gimbals. The RF generator (RF head) combines target signature characteristics, ECM antenna pattern data, free-space RF path attenuation, illuminator antenna pattern data, seeker antenna patterns along with Doppler effects, unique threat system waveform modulation and actual or simulated ECM RF to produce signals for injection into the ECM receiver under test and the threat missile seeker. RF verification data is collected at the subsystem level to quantify achieved accuracies of each simulation element function to baseline and document subsystem performance. System level data is also collected to establish and document overall simulator performance.

(2) Validation Procedures and Tools

Validation is (according to AFI 16-1001) the degree to which the simulation is an accurate representation of the real-world from the perspective of the intended use of the simulation. For AFEWES HITL threat simulations, the "intended use" is to determine the effectiveness of a particular countermeasure technique in defeating a specific threat. So, validation must consider whether the methods used to operate the threat representative hardware as well as the methods used to present target, background, and countermeasures information to that threat representative hardware accurately represent the "real-world". To address validation, we use a mix of four validation methods: Benchmarking, Face Validation, Results Validation, and Sensitivity Analysis. A succinct description of these methods appears in a Joint Accreditation Support Activity (JASA) training document:

- *Benchmarking* - Comparison of simulation outputs with outputs of another simulation that is accepted as a "standard".
- *Face Validation* - Comparison of simulation design and outputs (under well defined conditions) with the expectations and opinions of subject matter experts (SMEs) in the simulation area of interest.
- *Results Validation* - Comparison of simulation outputs with the results of test measurements made under identical input conditions.
- *Sensitivity Analysis* - Determination of the variation in simulation outputs for measured changes in inputs, functional operations, or other conditions (generally used to supplement other validation methods).

Each of these approaches has value but also has significant limitations. The lack of an accepted standard, the fundamental subjective nature of expert opinion, as well as insufficient, irrelevant or inappropriately instrumented test measurements, all contribute to the difficulty in proclaiming a simulation valid for an intended use. Validation is only as good as the ability to effectively identify and describe the intended use of the simulation and keep the verification current. AFEWES verification currency is maintained by extensive configuration management (CM) procedures and documentation. The AFEWES CM process is conducted by the technical contractor and is consistent with ISO 9001. For each simulator, appropriate regression testing and analysis is accomplished when an item is changed in the configuration baseline. In order to understand the fidelity of input data required for a specific intended use, AFEWES follows the earlier described logic to create and conduct Sensitivity Analyses.

(3) The consequential effects of this circumstance

Our continued diligence in pushing to gain and maintain a credible approach to V&V for AFEWES simulations will result in effective support of RF and IR countermeasures programs and ultimately the warfighter. V&V efforts are neither easy to accomplish nor inexpensive, but the increased survivability of America's combat aircraft far outweighs the cost.

e) Measures of Success.

AFEWES supported the Large Aircraft Infrared Countermeasures (LAIRCM) program by conducting more than 9000 HITL simulated missile engagements in FY02. Air Force Operational Test and Evaluation Center (AFOTEC) personnel spent more than

500 manhours working with AFEWES engineers, technicians and management to address more than 250 issues related to AFEWES IR HITL V&V. This effort resulted in AFOTEC accrediting AFEWES IR HITL simulations for combined Developmental/ Operational Testing--for the intended use of evaluating the LAIRCM LASER jammer effectiveness in defeating IR guided missiles.

The threat system experts adopted AFEWES RF missile calibration procedures, documented during verification data collection, as they prepared for live-fire testing.

f) Synopsis / Summary.

AFEWES investment (in terms of dollars, manhours, and relative management support compared to other activities) in V&V activities is at its highest level in many years. We expect to continue this emphasis for the foreseeable future because there has been a fundamental change in AFEWES capability in the last decade. We have moved from a mixture of Intel assessment-based simulators to two clear focus areas. These two areas are high-fidelity HITL simulation of RF semi-active (including seeker aided ground guidance) threats against blue RFCM and high fidelity HITL simulation of IR MANPADs and other passive IR threat missiles against blue IRCM (including flares, lamps and LASER jamming). In order to meet the needs of US EW programs we have moved from a purely Intel community-based validation approach to multi-service, multi-agency IPT-based verification and validation to provide credible HITL simulations and documentation.

2.4.3 Where Is AFWES Going?

Diligent use of Benchmarking and Results Validation (where there is available relevant and authoritative data) along with the use of the IPT approach, i.e. the fifteen points previously outlined (which is a form of Face Validation), makes sense. There remains in most cases, an area that is still difficult to address – that is the sensitivity of the simulation to model inputs. We propose that Sensitivity Analysis can fill the gap. If it can be determined by careful Sensitivity Analysis that a particular input to the simulation has very little impact on the outcome, one may submit that although the correlating piece of "truth" may not be known, it may not matter. Or if it does matter, one can appropriately articulate the limitations of the simulation and caveat the results.

a) Intention and Rationale.

Threat simulators do not function alone to provide an "answer" to the question "how effective is a US or allied electronic countermeasure system or tactic?" The fidelity of the various inputs to the simulation environment must be addressed. For RF missile simulations, these inputs include radar cross section (RCS), clutter, jet engine modulation lines, multipath, antenna patterns, electronic countermeasure (ECM) modes, depth of modulation and many others. The IR simulation is no less complex with target signature fidelity, source extension, spectral content, atmospheric attenuation, IR background and clutter, flyout model characteristics, as well as other inputs being potentially relevant. How does one know if a simulation is valid when "the truth" is either unknowable or an objective comparison is essentially impossible? Clearly, we believe that effective Sensitivity Analysis is necessary to validate threat HITL simulations. To this end, AFEWES is collaborating with Air Force, other Service, and DoD Intelligence Center subject matter experts to develop and conduct a series of Design of Experiments (DoE)-based data collection and analysis efforts to determine the output sensitivity of the AFEWES RF seeker aided ground guidance (SAGG) HITL threat representation to selected inputs. This effort is funded by the OSD Threat Simulator Investment Working Group (TSIWG) and is underway. A similar effort to evaluate the impact of input fidelity on the outcome of IR engagements is approved for funded by the TSIWG for FY03.

b) How We Are Going To Get There?

The methodology for AFEWES Sensitivity Analysis efforts is best understood by examining the RF SAGG SAM DoE study in more detail. The SAGG DoE study is led by HQ AFOTEC and has participation from an IPT of experts from some of the same organizations supporting our RF V&V IPT. The inputs to the AFEWES RF SAGG SAM simulation selected by the IPT for evaluation include: fidelity of the radar cross section, target conditions, glint, RCS magnitude, jet engine modulation effects, clutter, antenna pattern fidelity, missile launch position, and electronic countermeasures (ECM) dynamics. The approach of the experimental design is to first screen this list to identify those input factors with potentially significant impacts on the simulation outcome. Follow-on experiments will then be conducted to resolve confounding, characterize the nature of main effects and identify important interactions. The understanding gained by conducting the experiments should identify which inputs we need to know with great fidelity and which inputs may not need so detailed an understanding. The goal is to produce a set of guidelines for test planners and program offices. These guidelines should identify the level of fidelity needed for various inputs to the simulation. The guidelines may be different depending on the specific test question being addressed. This effort should also identify which inputs require more effort and resources to gain more detailed understanding. We believe this DoE sensitivity analysis V&V approach enhances the credibility of simulation outcomes (when conducted in accordance within the established guidelines for input fidelity) and supports accreditation of the simulation for specific test purposes. Specific objectives of the RF SAM DoE Sensitivity Analysis effort are:

- Identify important target modeling considerations with respect to monostatic radar signatures, bi-static radar signatures and glint.
- Estimate the extent to which victim components must be modeled.
- Identify the level of detail required to adequately model ECM antenna patterns and relative location.
- Identify situations where environmental modeling is important.
- Estimate if engagement geometry affects any conclusions.

c) Expectations.

We anticipate that the initial screening effort will be concluded and the associated report published by the end of CY02. Follow-on experiments have been identified and will be conducted as soon as possible.

d) Why Do We Want To Get There?

The conclusions of these experiments, along with Benchmarking by direct comparison to test data from other high-fidelity simulations and Results Validation by comparison to available live-fire information, form the basis for validation of the AFEWES RF seeker aided ground guidance SAM simulation.

e) What Do We Gain From Getting There?

AFEWES perhaps gains the confidence of potential test customers as a result of our diligence. Far more importantly, the understanding of ECM effectiveness against threat missiles will enable program decisions, which will put equipment on aircraft that fly in harm's way. There can be no greater reward than that a US aircrew member returns safely home from a mission because of what we learned about the effectiveness (or lack thereof) of EW equipment and tactics in HITL testing. Please contact the author for more details related to specific AFEWES HITL simulation capability and applicability.

2.4.4 What Is The Risk?

It may be that when the Design of Experiments analyses are completed we learn that the fidelity required for simulation inputs is so high that the data is either unobtainable or unaffordable. On the other hand, if we are not particularly careful, we may generalize the results of one Sensitivity Analysis and apply it inappropriately to an evaluation or test effort, missing some vital interaction. These are problems that face test and evaluation and modeling and simulation professionals daily. The saying "a fool with a tool is still a fool" definitely applies. We must be ever diligent to truly understand hardware-in-the-loop limitations as well as strengths to effectively use these powerful capabilities. We endeavor to manage these risks by involving experts from other Service test organizations and Intelligence centers. To us, V&V is not a one-time event; rather it is a continuous process in which we strive to provide the most credible tools to enhance aircraft survivability.

III. VV&A Issues Facing HWIL and Distributed Simulation Systems

3.1 Major Cross-Domain Issues

This section identifies major issues related to the HWIL and distributed simulation systems that are largely independent of the particular domains of application that have been discussed above. The two issues discussed herein follow rather form the attributes of HWIL and distributed simulation systems and are, therefore of general quite concern. In addition, they are of such general nature that their introduction here provides rather a zeroth-order basis for consideration of the more specific and particular issue topics that follow.

Defining attributes of HWIL and distributed simulation introduced earlier included the following: a) they contain in a meaningful way hardware (or other 'real' assets), b) that are a sample of one, c) that 'represents (*is*) itself', and therefore, d) they perceive (or assume) the passage of 'real' time. These characteristics, while definitive, do not yet exhaust the attributes that are influential upon the successful practice of VV&A. In particular, we want to emphasize the fundamental complexity of such systems, and pursue the implications of that inherent complexity for both technical and business practice, or enterprise operations facets of VV&A.

Before proceeding to address the nature of complexity of HWIL and distributed simulation systems, we prudently acknowledge that complexity is not exclusively associated with HWIL and distributed simulations, nor are all HWIL or distributed systems necessarily complex. Nevertheless, it is so evident from our experience – aside from any analytical inference – that HWIL and distributed simulation systems are highly correlated with expected forms of complexity that have relatively direct implications for VV&A. And, that the identification of some of those forms, their effects, and the opportunities to manage associated risks is well worth investigation.

Complexity, naturally, comes in a variety of 'flavors'. Merriam Webster's Collegiate Dictionary defines "complex" as: *"1. a whole made up of complicated or interrelated parts"*, and *"2. hard to separate, analyze, or solve"*; associated technical measures: "$-k \ln \Omega$"; and intuitive notions: 'hard to understand'; all pertain. Here we are concerned with the following forms of *technical complexity* for HWIL and distributed simulation systems:

- Structural (kinds of parts; numbers (cardinality) of parts;
- Types of relationships among parts;
- Numbers of relationships among parts;
- Kinds of informational interfaces;
- Numbers of informational interfaces;
- Location of components;
- Time- or circumstantial-variability of composition; etc.), and

- Behavioral (kinds of simulation executive operations / processes / methods, kinds of representation, numbers of representations, semantic variety and consistency of representations including ‘time’; etc. …).

Similarly, there exists, typically, considerable meta- or contextual-complexity associated with HWIL and distributed simulations. These too include structural (kinds of individuals, organizations, and roles active in the enterprise; intentions and expectations of stakeholders; relationships among stakeholders and their respective agendas; infrastructure investment availability and peculiarity; cost, value, peculiarity, and rarity attributes of components; etc.) and behavioral (custodial management of assets; collaborative planning and program management implementation; technical developmental and asset employment operational execution; etc.) elements.

The natural consequences of prevalence of complexity and concomitant success-risk for HWIL and distributed simulation VV&A can be summarized relatively succinctly in terms of two issues. The first – Technical Complexity Management – denotes the inhibition to successful VV&A arising out of the ensemble of features contributing to the direct complexity of the subject systems, e.g. ‘what they are’ and their technical implementation e.g. ‘how they are constructed’. The second – Enterprise Complexity Management – denotes, similarly, influence upon successful VV&A arising out of the meta- or indirect attributes of the enterprise within which much HWIL and distributed simulation occurs.

3.1.1 Technical Complexity Management

a. Description

The net effect of the forms of technical complexity cited above, are that VV&A practice is made more difficult or unsure in a variety of ways suggested in ***Table 3.1-1***.

Table 3.1-1. Implications Upon VV&A of Technical Complexity of HWIL and Distributed Simulation Systems.

Forms of Technical Complexity	Influence upon VV&A
Structural Forms:	
Kinds of parts (type variety).	Requires greater variety of V&V techniques.
Numbers of parts (cardinality).	Requires either more effort, or managed investment.
Types of relationships among parts.	Suggests alternative influence dynamics that must be considered and potential greater variety of V&V techniques.
Numbers of relationships among parts.	Requires either more effort or managed investment.
Kinds of informational interfaces.	Requires greater variety of V&V techniques.
Numbers of informational interfaces.	Requires either more effort or managed investment.
Location of components.	Suggests access constraints or need for spatial distribution of consistent operations.
Time- or circumstantial-variability of composition.	Requires careful configuration management and audit traceability of correlation between configuration and V&V determinations and findings
Behavioral Forms	

Table 3.1-1. Implications Upon VV&A of Technical Complexity of HWIL and Distributed Simulation Systems.

Forms of Technical Complexity	Influence upon VV&A
Kinds of simulation executive operations / processes / methods.	Requires effective discrimination between 'executive' and 'representational' function of the simulation asset, thorough identification of elements of the 'conceptual model of the user's space', and greater variety of V&V techniques.
Numbers of executive operations / processes / methods.	Requires either more effort or managed investment.
Kinds of representation.	Requires greater sensitivity to the significance of alternative representational schemas (scope, detail, fidelity, and mechanization) and greater variety of V&V techniques.
Numbers of representations.	Requires either more effort or managed investment
Semantic variety and consistency of representations including 'time'.	Requires extreme sensitivity to confirming not just syntactic consistency in V&V procedures, but to effective evaluation of semantic effect.

Note the family resemblance of 'type-variety' implications (technique influence) and 'cardinality' implications (effort management) that arise for both structural and behavioral forms of simulation asset intrinsic or 'technical' complexity.

b. Consequences

Clearly, there are implications of technical complexity that will influence cost, schedule, and product quality risk. Cost estimating relationships (CERs) are unclear as to the qualitative factors and the decencies they imply (a la COCOMO) that influence program cost for VV&A; but reasonable estimations are worse than linear with size and complexity, particularly since the sensitivity of VV&A determinations to errors of omission or misinterpretation is very high.

c. Candidate Solutions

In a sense, candidate solutions are obvious. If simulation systems are systems and if V&V are the evaluation components of systems engineering, then scrupulous systems engineering of the HWIL or distributed simulation system should facilitate VV&A and ameliorate some of the difficulties associated with operating in the context of technical complexity. Having practices deliberate requirements management conceptual model specification, configuration management in the development of the simulation system provides at least clear explication of the system's complexity for the sake of V&V investment. Particular processes (e.g. the Federation Development and Execution Process – FEDEP) and information assets (e.g. interface control documents – ICD) exist for that purpose. On the other hand, most of all mechanisms appropriate for Systems engineering of the given objective system itself or that typical of the enterprise process may be employed. Such re-use leveraging is likely to be all the more convenient given HWIL usage and the prospect of consistent forms of technical management tools at the levels of objective system and simulation system. Finally, aggressive implementation of the techniques indicated in the introduction of this paper - namely, the use of the Evaluation Kernel, and adherence to the Managed Investment Strategy – should be effective in this respect.

d. Value

The value of such amelioratives is relatively evident in the area of risk management control.

3.1.2 Enterprise Complexity Management

a. Description

In analogy to the analysis of technical complexity above, enterprise complexity can be seen to characterize HWIL and distributed simulation, to influence the difficulty of VV&A practice and to admit to some systematic amelioratives. Enterprise in this context denotes the full set of stakeholders, their interests, their relationships, and their behaviors in which environment the VV&A of HWIL and distributed simulation system assets is conducted.

As before, the net effect of the forms of enterprise complexity cited above, are that VV&A practice is made more difficult or unsure in a variety of ways suggested in ***Table 3.1-2***.

Table 3.1-2. Implications of the Enterprise Complexity Upon VV&A of HWIL and Distributed Simulation Systems.

Form of enterprise complexity	Influence upon VV&A
Structural forms:	
Kinds of individuals, organizations, and roles active in the enterprise.	Multiplicity of role types, especially when executed by different organizations, requires particularly explicit denotation, specification and execution.
Intentions and expectations of stakeholders.	Role holders having diverse intentions and expectations in establishing and executing VV&A programs is untenable.
Relationships among stakeholders and their respective agendas.	Relationships among stakeholders and their respective agendas must at least admit to win-win, non-zero-sum, and certainly non-adversarial consensus appreciation.
Infrastructure investment availability and peculiarity.	Sunk cost in infrastructure for HWIL and distributed simulation development, integration, and consequently VV&A, including facilities and accessories qualification investment will likely strongly influence VV&A programs specification and execution.
Cost, value, peculiarity, and rarity attributes of components.	Similarly, cost and availability of distributes simulation assets and HWIL components will constrain VV&A task management – particularly when distributed assets are used for more than one simulation ensemble, or when HWIL assets are in limited supply in the subject program.
All.	Note: in all cases, unusual coordination, often facilitated by an ad hoc administrative mechanism (e.g. IPT, etc.) is necessary for constructive efficient and effective coordinated activity within the enterprise to accomplish shared VV&A agendas.
Behavioral forms	
Custodial management of assets.	Who owns what part of the HWIL / distributed simulation system and how it is controlled necessarily influence how its advocacy as a credible contributor to the larger system is managed – perception of risk in misrepresentation of

Table 3.1-2. Implications of the Enterprise Complexity Upon VV&A of HWIL and Distributed Simulation Systems.

Form of enterprise complexity	Influence upon VV&A
	objective system components and consequent aggressive control of data artifacts is inevitable.
Collaborative planning and program management implementation; etc.	Enterprise-wide participation in VV&A planning and consensus on agreed-upon implementation programs is difficult, but necessary.
Technical developmental and asset employment operational execution.	Expectation of cooperation in developing and using subject HWIL and distributed simulation assets is a powerful incentive to participate liberally and attentively to the VV&A process.

Enterprise complexity entails facilitating cooperation amid a wide variety of encumbrances, most of which have to do with resource pressure and incommensurable agendas. Cooperation, like all forms of order requires investment of 'energy' and discipline. VV&A activity no less than developmental or operational activity (sometimes more given the evaluation-credibility implications of VV&A) is influenced by the effectiveness of the management enterprise.

b. Consequences

Overt uncooperativeness in VV&A in complex environments such as HWIL or distributed systems is rare, but the 'load' on the VV&A program of enterprise class inhibition can be equally deadly.

c. Candidate Solutions

Just as simulation systems admit to systems engineering techniques, so do VV&A program s admit to admit to general program management techniques. Deliberate enterprise management with emphasis on consensus-building and Pareto optimal investment of stakeholders' contributions is, however, essential.

d. Value

As above, the value of such amelioratives is relatively evident in the area of risk management control.

3.1.3 Shortfall in Telecommunications Infrastructure for Distributed Simulations

a) Description

In 2001, The RDEC Federation, including the APEX Lab, conducted a CALibration EXperiment (CALEX) to determine the ability of the US Army to perform long-haul HLA experiments of analysis-quality. The CALEX identified and experienced the VV&A performance risks associated with long-haul HLA analysis. Factors include the number of sites, number of federates, duration of scenarios, instability of wide-area networks, fragility of federations, and federate differences in optimal settings. These factors were significantly high during the CALEX, to the extent that long-haul record runs were not possible.

b) Consequences

With the loss of the old Distributed Simulation Internet (DSI), the Army has lost the capability to perform long-haul distributed simulation without purchasing dedicated lines or operating across a general-purpose network such as DREN. The current state of performance using HLA and DREN precludes long-haul analysis and experimentation of the scale needed for the RDEC Federation. Performance of the RDEC Federation across general-purpose networks is expected to improve, but remain marginal, in the near-term. This problem extends cross-domain to other upcoming simulations such as WARSIM and JSIMS.

c) Candidate Solutions

The risk factors mentioned above must be mitigated to the degree that record runs can be executed. Short-term solutions are to revert to co-locating equipment and people. Long-term solutions must include building stability and resilience into the architecture elements.

d) Experiment Approach

Resources have been budgeted starting in FY03 to address RDEC Federation performance and infrastructure. Efforts are underway now to streamline DREN connectivity at each site to minimize Metropolitan Area Network (MAN) nodes and bottlenecks. HLA Run-Time Infrastructure (RTI) fragility has been highlighted to the Defense Modeling and Simulation Office (DMSO) and to the Parallel and Distributed Simulation community as a critical issue. Near-term solutions may require co-locating critical federates.

e) Value

The RDEC Federation, and architectures like it, is critical to the development and assessment of the Army's Future Combat Systems (FCS) and the Objective Force. Collaborative simulation from integrated facilities is the only way the Army can fully implement the SMART process, and support multiple customers without duplication of resources and expensive travel costs for experimentation.

3.2 Selected Domain-Specific Issues

This section identifies selected VV&A issues related to the HWIL and distributed simulation systems that are pertinent to primarily a single application domain; e.g. Army, Navy or Air Force. A description of the issue, its consequences, candidate solutions for amelioration, experiment approach and value in such an enterprise will be discussed in the sections below.

3.2.1 US Army - Aviation & Missile Command

a) Description

While the VV&A processes for HWIL and distributed simulations have been described in above sections of this paper, assumptions have been made that validation is possible by making (small) adjustments to the simulation models to achieve agreement between measured data and simulation results. However, the possibility exists that the simulation is so unrepresentative that (i) validation is not achievable without drastic restructuring and re-design of the simulation, or (ii) that changes to the simulation model have been made that produce the desired comparison between measured data and simulation results and satisfy validation criteria for a particular set of measured data but the adjustments are physically and mathematically unrealistic.

b) Consequences

The result of eventuality (i) is that considerable time and effort may be spent before the realization of the inadequacy of the simulation becomes apparent, while for eventuality (ii) validation may appear to be achieved based on a particular set of measurement data, but the model is not robust enough for results to be credible across a wide range of parameters and scenario variations.

c) Candidate Solutions

Solutions to issues described include (i) M&S and VV&A experience to combat the design of inadequate simulations; (ii) use of as wide a range as possible of measured data for performance of VV&A and the division of the simulation in modules and sub-systems for validation at this level before applying validation processes at the overall system level. Validation of sub-systems and modules individually prevents the feedback interactions of a closed-loop system in which the effects of changes to a sub-system model affects results for all other modules.

d) Experiment Approach

Validation should be considered a continuous process throughout the life of the simulation and applied continually when new data become available.

e) Value

With such a continuous process the credibility and utility of the simulation increases as a function of time.

3.3 Residual (Lesser) Issues Impacting M&S VV&A

Summarized below are additional, residual issues that may impact HWIL and distributed simulation VV&A, as well as the use of these kinds of simulations in the problem solution space. Potential amelioratives are suggested, which may mitigate their impact on V&V execution, as well as on the simulation application.

For purposes of discussion and ease of treatment these issues which bear on successful accomplishment of HWIL and distributed simulation V&V and, ultimately, M&S accreditation and acceptance, have been sorted (imperfectly) and aggregated into several functional categories:

- *Systems Engineering*-related issues
  - Communications
  - Timing and synchronization
  - Interfaces
- *High Performance Computing (HPC) and Software Engineering*-related issues
- *Validation Process*-related issues

- General V&V processes
- Hardware validation
- Digital Model validation

- *Operations*-related issues
  - Technical operations
  - Enterprise operations
  - Expectation management

Each of these categories are addressed in the sections below.

3.3.1 Systems Engineering Related Issues Impacting M&S VV&A

Systems engineering (SE), and the attendant M&S requirements that devolve from its exercise, potentially affect the overall success of the HWIL or distributed simulation enterprise. The M&S requirements and the issues associated with systems engineering must be met and overcome during the development, integration and test of the HWIL or distributed simulation system. Careful consideration of these requirements, much like VV&A itself, will influence the outcome of the development activity. All M&S have design requirements and should implement a rigorous systems engineering process to accomplish them, but, because of their nature and make-up, HWIL and distributed simulations have to invest particular attention to. The VV&A of the design and implementation that results from that process must also be focused on these aspects of the HWIL and distributed simulation.

Systems engineering related VV&A issues associated with communications, timing and synchronization, and internal and external interfaces are addressed in ***Tables 3.3-1, 33-2,*** and ***3.3-3***, respectively.

Table 3.3-1. Residual Systems Engineering-Related VV&A Issues On Communications.

TOPIC	DESCRIPTION	CONSEQUENCES	RESEARCH TOPICS / SOLUTION(S)
SYSTEMS ENGINEERING			
Communications Issues			
Bandwidth Requirements	Bandwidth requirements and limitations potentially affect HWIL validity. HWIL and SWIL used in simulations must interface / interact within the synthetic simulation environment.	This requirement imposes significant bandwidth requirements on the simulation system.	Enable new approaches for HWIL and distributed simulation operations through additional investment in infrastructure to promote information sharing, and collaboration.
Encryption Constraints	Integration of tactical hardware, software, and C3 systems often bring with them issues associated with providing a secure information environment.	This may impose a requirement on the simulation to address encryption, and the need to V&V encryption mechanisms.	Development of V&V practices for encryption schemas used in HWIL and distributed simulations.
Distributed Operations	Distributed simulation operations potentially introduces additional challenges associated with meeting the real-time, bandwidth, and encryption constraints previously discussed.	Actual feasibility of executing distributed operations (distributed simulation).	Investments in Network Centric Warfare-related research and technologies will provide the necessary understanding and tools to support V&V of HWIL and distributed system simulations supporting systems acquisition. Training of individual, team, organizations on the V&V

Table 3.3-1. Residual Systems Engineering-Related VV&A Issues On Communications.

TOPIC	DESCRIPTION	CONSEQUENCES	RESEARCH TOPICS / SOLUTION(S)
SYSTEMS ENGINEERING			
Communications Issues			
			activities used in HWIL and distributed simulation programs will significantly accelerate progress.
Limitations of Commercial Telecommunications Technology	Commercial telecommunications technology and computer communications protocols used by JADS (as well as DIS and HLA) do not support the transmission of native spectrum environment data.	Analog waveforms can be captured digitally and transmitted over commercial telecommunications lines using computer communications protocols.	Development and documentation of efficient V&V methods that facilitate the evaluation of native spectrum environmental data against the analog (and digital) representations used in HWIL and distributed simulation systems is needed.
Transmission of Native Spectrum Environment Data	Techniques currently used for transmitting analog and electromagnetic waves in local distributed simulation facilities such as RF waveguide and fiber optic links are not affordable for geographically separated facilities.	If entire digitized waveforms are being transmitted, bandwidth quickly becomes an issue.	Tools to evaluate bandwidth requirements are needed to enable early trades regarding simulation fidelity versus detail.
Handling Data Loss	Event data cannot be predicted. Data loss must be addressed in simulation experiment and test design. JADS lost far less than 1% of all data transmitted, however data loss depends on several factors. JADS EW Test showed that the lowest latency computer communications protocol consistently showed the highest data loss.	Event data must be sent using more reliable but higher latency computer communications protocols, or transmitted multiple times, or transmitted with periodic data from the same player, or event data losses must simply be accepted.	Development and documentation of efficient V&V methods and tools to capture rates of data loss, and latencies provides quantitative means of evaluating the robustness of communications within HWIL and distributed simulation systems.
Use Of Dedicated Links.	Because of latency, reliability, and scheduling requirements, the use of dedicated, leased telecommunications lines have to be justified, rather than using existing networks such as Defense Simulation Internet (DSI).	If dedicated lines are not available, HWIL and distributed simulation operations will be impacted in terms of latency, reliability, and scheduling requirements.	Each distributed simulation application must evaluate its requirements and justify the use of commercial links when appropriate.

Table 3.3-2. Residual Systems Engineering-Related VV&A Issues on Timing and Synchronization.

TOPIC	DESCRIPTION	CONSEQUENCES	RESEARCH TOPICS / SOLUTION(S)
SYSTEMS ENGINEERING			
Timing & Synchronization Issues			
Real-Time Constraints	Real world system software used in HWIL simulations generally executes on the real-world system's processors.	This requires the simulation environment to meet the run-time (execution rates) of the processors-in-the-loop. If the simulation cannot meet the processors' run-time, then the simulation may fail.	Development and documentation of efficient V&V methods and tools to capture data rates and latencies will provide a quantitative means of evaluating the robustness of communications within HWIL and distributed simulation systems.
Digital Simulation Model Constraints Impacting Distributed Testing	Digital simulation models (DSMs) must work in real time to usefully link with hardware- and software-in-the loop simulations, manned simulators, threat simulators, manned operator stations, and other real-time simulations of blue or red players. Inability of DSMs to meet run-time requirements of the processors and SWIL will result in failure of the HWIL simulation to operate reliably.	Oftentimes, these models are executed off-line (like a pre-processor) to generate the inputs data needed.	The consequences of using pre-processed data in a dynamic simulation must be evaluated in terms of discrete event management. The development of V&V techniques to capture and compare differences associated with operating in this manner is needed.
Latency in Distributed Simulations	Latency is a limitation on how tightly two players can be coupled. For example, the distributed simulation architectures used in JADS EW testing were capable of average round-trip transmission latency for HLA "reliable" (transmission control protocol [TCP]/Internet protocol [IP]) interactions of 254 and 167 milliseconds respectively. "Best effort" (user datagram protocol [UDP multicast) latency was considerably better, and the architecture could have supported round-trip transmission latency of less than 100 milliseconds if JADS had used this protocol.	Inability to meet run-time requirements may result in failure of the distributed simulation to operate reliably.	A standard means to measure and establish the "tolerable" latency in HWIL and distributed simulations is needed.
Handling Out-of-Sequence Data	Out-of-order (out-of-sequence) data are a distributed simulation effect that must be addressed in experiment design.	Differences in transmission methods, differences in distance, and the one-device-at-a-time nature of some computer communications protocols are all contributing factors that may diminish the ability to execute distributed simulations effectively	V&V agents need to be aware of these sources and deal with them in the design of V&V Plan, V&V data collection, and V&V data analysis

Table 3.3-3. Residual Systems Engineering Issues VV&A Relating to System Interfaces.

TOPIC	DESCRIPTION	CONSEQUENCES	RESEARCH TOPICS / SOLUTION(S)
SYSTEMS ENGINEERING			
System Interfaces Issues			
HWIL Interfaces	Difficulties may exist in meeting HWIL interfaces between simulation hardware and software, and the tactical (prototype) hardware and software integrated into the simulation.	Simulation and tactical systems may not be interoperable.	Development of standards relating to interfaces between tactical systems and simulations are needed to facilitate the incorporation of tactical hardware (and software) as players within HWIL and distributed simulation systems.
Specifications For Linking Threat And Environmental Simulators	The specifications for linking threat and environmental simulators activities must provide for additional types of quality assurance instrumentation to monitor the environmental and threat representations at each location.	Subtle differences in the waveform representations among locations have the potential to change how each player behaves in the scenario and may impact the distributed simulation results.	Development of standards relating to interfaces linking threat and environmental simulations and simulators are needed to facilitate simulation interoperability and re-use.

3.3.2 High Performance Computing and Software Engineering Related Issues Impacting M&S VV&A

The advent and adoption of high performance computing (HPC) machines and their associated software engineering and implementation methodologies are influencing HWIL and distributed simulation design, development, integration, test and execution. M&S VV&A processes and practices have had to adapt to this new technology as well and develop associated tools, techniques and procedures associated with the verification of simulation and tactical software that is parallel, multi-threaded, and network-centric. These HPC and software engineering topics are addressed ***in Table 3.3-4***, below.

Table 3.3-4. HPC and Software Engineering-Related Issues Impacting M&S VV&A and Potential Amelioratives.

TOPIC	DESCRIPTION	CONSEQUENCES	RESEARCH TOPICS / SOLUTION(S)
HPC / SW ENGINEERING ISSUES			
Parallel Processing	Many HWIL simulations are intended to be deterministic. However, parallel processors and software increasingly are *used in the simulation* to generate the synthetic natural environment. This contributes to run-to-run variability in the simulation results.	Analysis results and findings can be confounded due to the increased variability due to the use of parallel simulation processors in simulations.	V&V methods and techniques that address the multiple paths, and associated run-to-run variability, found in complex, parallel processor simulations need to be established, documented and promulgated to the community.
	Many HWIL simulations are intended to be deterministic. However, massively parallel processors and software are increasingly being *used in tactical systems* and these systems are being integrated as players in HWIL simulations, distributed simulation systems and test beds.	Analysis results and findings can be confounded due to the increased variability due to the use of parallel simulation processors in tactical systems.	V&V methods and techniques that address the multiple paths, and associated run-to-run variability, found in complex, parallel processors used in tactical systems need to be established, documented and promulgated to the community.

3.3.3 Validation Process Issues Impacting M&S VV&A

The emergence of conceptual models and their use in simulation design, implementation, and verification methodologies are impacting HWIL and distributed simulation validation processes. Validation issues relating to "what is under test – the simulation or the tactical system represented in the HWIL?" as well as the variability, or lack of variability, of the hardware used in the simulation also impact the validation processes for HWIL and distributed simulation systems. The distribution of a common synthetic environment in distributed simulations also compounds the difficulties of validating these systems. M&S VV&A processes and practices have had to adapt to these new technologies and the challenges they pose. These validation process-related topics are addressed in ***Table 3.3-5***.

Table 3.3-5. Validation Process-Related Issues Impacting M&S VV&A and Potential Amelioratives.

TOPIC	DESCRIPTION	CONSEQUENCES	RESEARCH TOPICS / SOLUTION(S)
VALIDATION PROCESS ISSUES			
General			
Conceptual Models	Relationship of a unary conceptual model of the *mission-space* (real world of the operating objective system) to the unary conceptual models of the *simulation representation domains*	Class inheritance within conceptual models and associations to system functions whose representation are subject to V&V.	
Identification of UUT	There must be an unambiguous identification and denotation of the Unit-Under-Test. (UUT) to ensure V&V evaluation activities are properly focused.	Without identification of the UUT, V&V activities may not be properly focused, and as a consequence not provide data needed for an accreditation decision.	Uniform means of explicitly identifying the unit under test are needed.
Hardware-Related			
Serial Number To Serial Number Variability	There may be significant serial number-to-serial number variability of hardware used in HWIL simulations.	Significant serial-number to-serial number variability of hardware used in HWIL simulations can confound HWIL results.	Studies to evaluate the consequence of serial number variability and the implications of drawing conclusions about a population based on a single sample would be beneficial.
Validation Of HWIL Used In Simulation.	Is validation of HWIL integrated into the simulation within the scope of the HWIL VV&A program, or just incidental to it?	How do you know you have representative hardware in the HWIL simulation?	Specification of the scope of the VV&A effort across DoD HWIL M&S would be helpful in establishing sufficiency of the effort.
Use Of Prototype HWIL / SWIL	Difficulties exist in establishing the credibility and acceptance / accreditation of HWIL-generated data that use *prototype* tactical HWIL and SWIL and the extrapolation of that data to performance predictions for the deployed system. The risk of committing a Type I Error is high [simulation results are rejected although in fact they are credible].	Committing this type of error unnecessarily increases the cost of M&S development and M&S V&V as even more extensive V&V activities may be executed to obtain a favorable accreditation decision.	Application requirements must be very clear, and the simulation results must be carefully considered against these requirements.

Table 3.3-5. Validation Process-Related Issues Impacting M&S VV&A and Potential Amelioratives.

TOPIC	DESCRIPTION	CONSEQUENCES	RESEARCH TOPICS / SOLUTION(S)
Digital Model-Related			
Synthetic Environment Fidelity	While advanced distributed simulation (ADS) provides the ability to use resources across facilities, the fidelity of the resulting environment is limited by the fidelity of the test infrastructure to create (represent) each piece of the environment.	Fidelity of the synthetically generated signals is limited to the capability of the simulator / stimulator connected to the unit-under-test, threat, or other players in the scenario.	This is not unique to distributed simulation test environments. The fidelity of the environment is always a constraint and must be addressed in the V&V program design as well as the V&V data analysis and assessment of results.

3.3.4 Operational Issues Impacting M&S VV&A

Additional issues impacting M&S VV&A planning and execution for HWIL and distributed simulation systems include operational issues. Topics relating to M&S facility technical operations, enterprise operations and expectation management of potential users are discussed in greater detail in Tables ***3.3-6, 3.3-7***, and ***3.3-8*** respectively.

Table 3.3-6. Technical Operations-Related Operational Issues Impacting M&S VV&A and Potential Amelioratives.

TOPIC	DESCRIPTION	CONSEQUENCES	RESEARCH TOPICS / SOLUTION(S)
OPERATIONAL ISSUES			
Technical Operations			
Simulation Reliability	The expected reliability of a distributed architecture is the product of the expected reliability of each component, resource, and facility. The reliability of each simulation component, resource, or facility has to be factored into the distributed simulation design.	As such, reliability can generally be expected to decrease as the number of components or players increase.	
Unique Skill Set Needed To Support Distributed Simulation Development, Integration, Test and VV&A	Distributed simulation experiments require skills not found in traditional simulation and test.	Lack of requisite skills will hinder and potentially prevent successful distributed simulation operations.	Training in nontraditional M&S VV&A skills including: wide area computer network design, integration, test, and operation; local area computer network/wide area computer network integration and optimization; computer / simulation interface design, integration, optimization, and test; and if HLA is used, then Run Time Infrastructure experience, and local area network (LAN) and wide area network (WAN) installation, optimization, and operation
Early Testing Against HWIL Threats	Early testing against HWIL threats is likely to increase test program costs over the current DoD test process design.	However, early testing against HWIL threats should uncover problems earlier in the weapon system development cycle.	Ultimately, increased costs will have to be weighed against the improved test realism benefit, the potential improvements in test capability through the networking of existing facilities, and the potential of cost avoidance.

Table 3.3-6. Technical Operations-Related Operational Issues Impacting M&S VV&A and Potential Amelioratives.

TOPIC	DESCRIPTION	CONSEQUENCES	RESEARCH TOPICS / SOLUTION(S)
Systems Integration	There are non-standard processes associated with the integration of HWIL simulations and distributed simulations. Efficiency in operations and technical operations mandate a formal integration and execution process.	The absence of formal specifications for simulation integration and execution require each simulation enterprise to invent (and re-invent) their own practices.	Development of best practices associated with simulation integration and execution for HWIL and distributed simulations potentially would reduce costs, and increase efficiency and effectiveness.

Table 3.3-7. Enterprise Operations-Related Operational Issues Impacting M&S VV&A and Potential Amelioratives.

TOPIC	DESCRIPTION	CONSEQUENCES	RESEARCH TOPICS / SOLUTION(S)
OPERATIONAL ISSUES			
Enterprise Operations			
Resource And Facility Limitations	Understanding resource and facility limitations is critical to experiment (test) design. Connecting facilities for distributed simulation operations tend to highlight these limitations. Each resource or facility brings its inherent errors, limitations, and assumptions into the test architecture.	V&V of the players and the architecture are essential. Again, this is not unique to distributed simulation experiment designs. However, it is important that limitations be known up front to ensure the best quality environment is created.	These errors, limitations, and assumptions must be identified and managed in the experiment design to avoid problems with increased data variance and/or decreased test validity.
Limited Availability / Number of Distributed Simulations	Executing distributed simulation operations is limited by the availability of suitable simulators and environment representations in HWIL and ISTFs.		
Limitations of Existing HWIL Facilities to Support Distributed Tests	Existing EW and HWIL facilities are challenged in implementing advanced distributed simulation-based tests. Most existing facilities were designed to perform stand-alone tests.	Facility details such as the ability to time synchronize the entire facility and internal latencies that are not a factor in traditional tests are critical in distributed simulation experiments.	Facilities will have to investigate and document design details that may have been made decades earlier, and it forces facilities to reveal more of their internal workings than they are accustomed to revealing.
Additional Costs Associated With Distributed Simulation Systems	There are significant costs associated with the implementation of distributed simulation systems. For example, JADS found the single largest cost for implementing distributed simulation experiments to be the cost of modifications to existing EW and HWIL facilities to allow them to inter-connect.	Cost associated with implementation of distributed simulations may be significant and an inhibitor to the utilization of distributed simulations.	

Table 3.3-8. Expectation Management-Related Operational Issues Impacting M&S VV&A and Potential Amelioratives.

TOPIC	DESCRIPTION	CONSEQUENCES	RESEARCH TOPICS / SOLUTION(S)
OPERATIONAL ISSUES			
Expectation Management Issues			
Preferential Use of HWIL Simulations	Certain agencies have a pre-disposition to "accept" HWIL simulation data since the simulation incorporates elements of the "Real-world" system. These agencies are not sensitive to the issues that arise with HWIL M&S. False expectations of simulation validity because they incorporate HWIL are established. An increased risk of committing a Type II Error [invalid simulation results are accepted, even though they are not sufficiently credible].	Committing this type of error can be catastrophic. This is especially true if key decisions are based on the M&S results.	Like the Type I Error, the Type II Error is best avoided by completely understanding the application requirements and carefully considering simulation results.
Simulation Is Easier Than Physical Testing	While advancing the use of M&S, some proponents express the notion that simulation is easier and less expensive than physical tests.	False expectations of what simulations can do and at what cost may be established.	

IV. MAJOR VV&A RESEARCH AREAS FOR HWIL AND DISTRIBUTED SIMULATION SYSTEMS

Research topics derived from the forgoing analysis of HWIL and distributed simulation systems VV&A are roughly categorized below as pertaining to one or another sets of issues from which their consideration arose. The identification of candidate research topic and the selection of preferred candidates followed relatively systematically from the proceeding review. Each issue identified above was considered to see what research or new knowledge was required for its resolution. Then, research topics were consolidated, as several research interests pertained to more than one issue topic. Finally, the research topics themselves were prioritized according to the following criteria:

a) Need for investigation of the topic (How original was the topic – how much work already has been done in this area?)

b) Tractability as a topic of investigation (how hard is the topic to pursue? How likely were significant findings?)

c) Focused relevance to HWIL and distributed simulation systems' VV&A (To what degree is the topic pertinent to HWIL and distributed simulation .AND. to VV&A in particular?)

For each topic considered at least reasonably desirable, plausible, and relevant, comments are provided in the tables below:

- Table 4-1. Simulation System Architecture Specification.
- Table 4-2. Conceptual Model Specification.
- Table 4-3. Encryption Implementation V&V. Specification.
- Table 4-4. Communications Latency Management.
- Table 4-5. Communications Latency Management.
- Table 4-6. Parallel Processing Implications.
- Table 4-7. Simulation-Systems Integration Process.
- Table 4-8. Cost Benefit-Analysis and HWIL / Distributed Simulation Investment Criteria.
- Table 4-9. Enterprise Management.

Table 4-1. Simulation System Architecture Specification.

Topic Title:	Simulation System Architecture Specification
Research Need:	Need exists to regularize the practice of specifying the compositional architecture of simulation systems to facilitate the identification and appreciation of structural features of the complex simulation system and their associated architectural relationships and behaviors. No such generally recognized practice exists, inhibiting VV&A of technically complex simulation systems.
Research Activity:	Review techniques and supporting tools for specification of (HWIL distributed simulation) systems architectures. Evaluate alternative approaches for establishing the compositional architecture of HWIL and distributed simulation systems in particular. Draft recommended practice.
Desired Results:	Standards, tools (notations and COTS products), and techniques necessary and sufficient to systematically document the compositional architectures of complex HWIL / distributed simulation systems.

Table 4-2. Conceptual Model Specification.

Topic Title:	Conceptual Model Specification
Research Need:	Need exists to document conceptual models of components of HWIL and distributed simulation systems, particularly in regard to model detail and semantic consistency. No such generally recognized practice exists, inhibiting VV&A of technically complex simulation systems.
Research Activity:	Review techniques and supporting tools for specification of HWIL / distributed simulation systems component conceptual models. Evaluate alternative approaches for establishing the specification of conceptual model detail and consistency of semantic significance between simulation system components. Draft recommended practice.
Desired Results:	Standards, tools (notations and COTS products), and techniques necessary and sufficient to systematically document the conceptual models of components and ensembles of complex HWIL / distributed simulation systems.

Table 4-3. Encryption Implementation V&V. Specification.

Topic Title:	Encryption Implementation V&V
Research Need:	HWIL and distributed simulations frequently require encryption functions. These simulation executive functions need to be verified in accordance with relevant informational security policies and procedures as well as with respect to simulation implementation correctness and operational credibility. No generally satisfactory and widely appreciated practices exist to meet these requirements for encryption component / function verification.
Research Activity:	Review verification requirements for encryption components and functionality in HWIL and distributed simulation systems. Evaluate alternative approaches for establishing the acceptability of these components and functions from both the information security and simulation credibility perspectives. Draft recommended practice.
Desired Results:	Establishment and general acceptance of processes, procedures and techniques necessary and sufficient to establish the correctness of implementation of encryption in simulation systems.

Table 4-4. Communications Latency Management.

Topic Title:	Communications Latency Management
Research Need:	The need exists to manage communications latency among components of HWIL / distributed simulation systems. Latency management includes: a) evaluation of acceptable / tolerable data transport latencies, b) prediction of likely latencies in simulation systems along with their likely effects, c) observation / measurement of actual latencies and their consequent causal effects particularly as they impact verification and validation evaluation, and d) amelioration of data latency induced effects on V&V vis-à-vis control of observed simulation behaviors relative to V&V criteria.
Research Activity:	Some research is imagined possible for each area of latency management indicated, although some are ostensibly more relevant to VV&A than others, whose implications for system development may dominate. a. In order to support estimation of acceptable / tolerable data transport latencies, two elements of research are necessary. First, establishing reliable forms of prediction of transport latencies among diverse types of components, communicating across diverse communications infrastructure under control for diverse executive mechanisms is desired. Providing comprehensively available tools that can be tailored to the circumstances of distributed (and HWIL) simulation and that can predict (in accordance with the analytical research) node-specific latencies of message instances or types is practically necessary. Secondly, establishing generally appreciated and relevant latency tolerance criteria, parametrically contingent upon the circumstances of distributed and HWIL simulations, is necessary. b. In order to support prediction of probable latencies in specific systems, and their likely effects, there needs to be added to the latency-redetection capability indicated above, the explication of probable causal effects consequent to latency severity for each of several kinds of messages and component types. c. In order to facilitate observation / measurement of actual latencies and their consequent causal effects particularly as they impact verification and validation evaluation, recommended practice in latency measurement and recording is needed. Further, the causal chain of latency-to-effect needs to be extended to V&V implication so that the implication of measured latency upon V&V results can be educed. d. Finally, the practical use of latency and effects estimation for the sake of predicting consequential effects in simulation operation needs to be considered in context of qualifying the use of the simulation system for its intended use. Recommended practices for establishing such qualifying guidance are needed
Desired Results:	Systematic best practice, processes and accompanying tools necessary and sufficient to pro-actively manage latency and control its effects on simulation predictive credibility as well as to document resulting behaviors.

Table 4-5. Communications Latency Management.

Topic Title:	Management of Native-Spectrum Environmental Data
Research Need:	Environmental data is relatively dense, and is provided in a variety of formats, including time- and frequency-domain and in context of spatially and parametrically distributed manifolds. The systematic management of such high-volume and particularly formulated information is often challenging in HWIL simulations where the HWIL article is frequently sensitively dependent upon access to appropriately representative data in 'effective real time'.
Research Activity:	Investigate the data types and formats necessary for representation of environmental data in typical HWIL simulations, and establish processes, techniques and tools to support the management of such data - including its delivery to the HWIL article - in forms that will meet to within well-defined criteria requirements for data integrity appropriate for the several classes of HWIL artifact.
Desired Results:	Systematic best practice, processes and accompanying tools necessary and sufficient to pro-actively manage Environmental Data Management and control the effects on environmental data manipulation on simulation predictive credibility.

Table 4-6. Parallel Processing Implications.

Topic Title:	Parallel Processing Implications
Research Need:	While, many HWIL and distributed simulations are intended to be deterministic to within constraint of non-deterministic components (e.g. MIL), there are frequently parallel computational elements whose effects on repeatability and causal correctness may be relatively unappreciated or uncontrolled. Such computational elements - some in the simulation-representation domain, and some in the simulation-executive domain - may include: a) parallel processing used in the simulations to generate synthetic environments, b) parallel processors used within the objective system components that may be used as HWIL / SWIL components, and of course, c) parallel processing within the simulation executive to facilitate evaluate of digital representation, and d) the parallelism intrinsic on distributed and embedded simulation architectures themselves.
Research Activity:	Investigate the kinds of effects on predictive credibility that can result from the variety of parallel processes likely to be relevant to HWIL and distributed simulations. For each, establish the range of contingency circumstances wherein such effects can arise, identify indicators of such pathologies, educe possible consequences, and provide indications of possible amelioratives along with their applicability and effectiveness.
Desired Results:	Best practices guidance for managing the implication of parallel processes in HWIL and distributed simulation systems.

Table 4-7. Simulation-Systems Integration Process.

Topic Title:	Simulation-Systems Integration Process
Research Need:	Developmental integration of HWIL simulation systems strongly influences system developmental cost, efficiency and effectiveness. While processes have been established particularly to support the development of distributed simulation systems – that is the Federation Execution Development Process (FEDEP) – no similar guide to practice / process exists for HWIL simulation development.
Research Activity:	Explore the development life-cycle of HWIL simulation systems, and identify components of the developmental process that are particularly sensitive to the use of HWIL components and that may materially influence the cost-effectiveness of HWIL simulation development. Analyze these operational elements and develop guidance suitable to either: a) the modification / qualification of the FEDEP, or b) the establishment of a similar tailored process guidance for developmental integration of HWIL simulations.
Desired Results:	Best practices guidance for integrating HWIL simulation systems.

Table 4-8. Cost Benefit-Analysis and HWIL / Distributed Simulation Investment Criteria.

Topic Title:	Cost benefit-analysis and HWIL / Distributed Simulation Investment Criteria
Research Need:	While there are several areas of the economics that deserve investigation, the determination of cost-benefit of HWIL and distributed simulation systems and the establishment of "best-practices" for investment in those systems deserve particular attention due to the considerable cost typical of such systems. Identification of the cost (and utility) factors of HWIL and distributed simulations and the establishment of generally accepted accounting practices for reporting both the cost and benefit of such systems of their sometimes considerable life-time and range of application is subject to research and analysis. Guidance on how best to account for prospective cost and utility in making investment decisions likewise admits to systematic attention.
Research Activity:	Analyze the economics of HWIL and distributed simulation systems. Particularly identify dependencies on factors that differentiate HWIL and distributed simulation, and within that set of factors, address particularly those for which cost / benefit sensitivity is high. Account for the extended life cycle of HWIL and Distributed simulation assets and the incremental but sometimes disjoint investment and recovery timeframes. Identify cost and utility factors. Establish best practices for cost and benefit accounting. Establish procedural guidance for investment and investment recovery decision-making, providing explicit qualification of the relevance of such procedures to the parametric contingencies of the enterprise within which the subject investment is contemplated.
Desired Results:	Operational guidance for financial management-of and investment-in HWIL and distributed simulation assets.

Table 4-9. Enterprise Management.

Topic Title:	Enterprise Management
Research Need:	HWIL and distributed simulation requires generally more overt attention to ‘enterprise’ aspects than forms of simulation that have smaller constituencies, fewer roles, and lesser extent in sites, assets, and operations. In particular, the establishment of enterprise environments wherein all the significant participating agents can interoperate efficiently on terms that are generally appreciated as being win-win and risk-controlled is extremely important.
Research Activity:	Investigate and document the institutional dynamics of HWIL and distributed simulation operations, identifying the significant roles and relationships among participating agents and establishing criteria for successful collaborative participation among role-holders. Identify the dependencies of enterprise success on formal and informal roles and relationships, and indicate the forms of administrative and management control that are suitable for such operations.
Desired Results:	Operational guidance for enterprise establishment and operations in support of HWIL / distributed simulation systems development and operations.

V. CONCLUSIONS

5.1 THE CHALLENGE

As expressed in the introduction, the challenge of this effort was to determine what processes, techniques, and tools, beyond those that are normally available for VV&A are necessary for support of HWIL and distributed simulation assets Given the general context of the need and general practice for VV&A, the particular concern of this paper was to consider the special qualities of HWIL and distributed simulation assets, to analyze the peculiar requirements for VV&A processes, practices, and tools, and to identify both the problems and opportunities of dealing with VV&A of these special systems.

Specifically, we intended to address some of the very powerful strategies common to M&S VV&A practice and to consider how they particularly apply to HWIL and distributed simulation systems; then to survey a few characteristic HWIL and distributed VV&A loci in order to disclose a representative sample of particular tools, techniques and practices.

In meeting this challenge, we attempted to identify issues characteristic of V&V of HWIL, distributed simulations, and simulation frameworks and then propose ameliorative strategies. Finally, we addressed potential research topics and technologies to advance the state-of-the-art for validation of HWIL and distributed simulations.

For the sake of a shared context in which the subject analysis could proceed, a few cardinal strategies were introduced that served to anchor HWIL and distributed simulations VV&A to other forms of practice. These included: Accreditation-Requirements-Driven V&V Planning, the concepts of the V&V Evaluation Space, and the V&V Evaluation Kernel, and the business strategy of Managed Investment. Subsequent discussion used these cardinal points-of-reference to relate VV&A for HWIL and distributed simulation systems to that for other types of systems by means of both comparison and contrast.

5.2 DISCOVERY

Discovery of the nature of VV&A for HWIL and distributed simulation systems occurred in the context of the contributors' particular operational emphasis. As expected, the revelation of many general principles as well as some illuminating discriminating features was particularly rich.

All the contributors recognized the implications of complexity and size of HWIL distributed systems for VV&A management. They all indicated the value of systematic process, and they all were sensitive to many of the peculiarities of VV&A for HWIL and distributed simulation systems. In addition, each of the participating organizations revealed the kind of sampling distribution that might reasonably be expected and appreciated to exist across organizational and operational domains.

The Army AMRDEC contributors emphasize the extreme variety of HWIL and distributed simulation systems requiring VV&A; they indicate that complete formality in defining and executing V&V is difficult but that tailoring to the needs of individual VV&A programs is tenable, and they emphasize the need for deliberate financial management of VV&A activities over the extended lifetime typical of many HWIL and distributed simulation systems operation.

The Navy contributors, representing both the particular perspective of NUWC WAF and the broadly general perspective of NAVMSMO, acknowledged the implications of organizational culture; emphasized attending to the interfaces between complex simulation system components; and reiterated the need to 'build-in' V&V to the simulation system development process.

The Air Force, AFEWES, perspective combines detailed technical analysis of V&V requirements and functional needs with enterprise-wide management strategies to achieve both the technical credibility necessary for accrediting complex EW systems as well as the consensus desired for the shared confidence in the use of such simulation systems. Deliberate, balanced technical assessment of simulation attributes conducted in context of management via integrated product teams composed from members of a variety constituencies are responsive to the clear perception of need for public and systematic VV&A processes.

Notwithstanding considerable variety of objective systems, and simulation systems assets within the purview of each of the participating organizations, all of the participating organizations contributed topical issues, and all collaborated to establish consensus across their respective domains of operations.

5.3 DETERMINATIONS AND FINDINGS

5.3.1 Issues

The variety and emphasis of issues raised in the subject analysis is suggested by the topical classification provided earlier:

- Systems Engineering
- High Performance Computing (HPC) and Software Engineering
- Validation Process
- Validation Operations
- Expectation management

Even a cursory inspection reveals concerns ranging from the detailed (communications protocols) to the general (system architecture) and from those that are fundamentally technical (HPC) to those that are more significantly related to the management, enterprise, and business-case. Consensus on these issues by all the participating contributors testifies to the ubiquitous diversity of VV&A for HWIL and distributed simulation.

5.3.2 Research Topics

Prospective research topics were evaluated with respect to criteria including: a) need, b) tractability, and c) focused relevance to HWIL and distributed simulation systems' VV&A. From the topical list thereby derived, it is evident that potential research in VV&A for HWIL and distributed systems is likely to be both diverse and challenging. Research opportunities were defined for each of the following:

- Simulation System Architecture Specification
- Conceptual Model Specification
- Encryption Implementation V&V
- Communications Latency Management
- Management of Native-Spectrum Environmental Data
- Parallel Processing Implications
- Simulation-Systems Integration Process
- Cost benefit-analysis and HWIL / Distributed Simulation Investment Criteria
- Enterprise Management

5.3.3 Implications / Actions

Given the detailed determinations and findings contained in the report and identified above, there remains the residual concern: "So what?". The establishment of intention to act in pursuing these topics to constructive ends is, as always, challenging. The pressures and exigencies of mission and day-to-day responsibility inhibit extensive systematic investment in VV&A research. Nevertheless, by aligning topics identified herein with ongoing M&S R&D threads of activity, the pursuit of knowledge relevant to VV&A for HWIL and distributed simulation systems may be leveraged. In particular, ongoing program initiatives such as Grand Challenges, the research programs of universities offering advanced degrees in topics related to modeling and simulation, and the SimSummit Research line item offer such opportunities.

While the issues and potential research topics educed by this analysis are considered relevant and valuable, the concern persists that without extraordinary effort to pursue the establishment of a viable program of research for M&S VV&A, the net effect of the Foundations 02 will be to document the 'as-is' state of M&S VV&A – admirable, but not all that could be hoped for!

VI. HWIL AND DISTRIBUTED SIMULATION VV&A BIBLIOGRAPHY / REFERENCES

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