Verification, Validation, and Accreditation (VV&A) Automated Support Tools

A State of the Art Report
Part 1 – Overview

Modeling and Simulation Information Analysis Center (MSIAC)

December 15, 2000

This report was prepared by the Modeling and Simulation Information Analysis Center, the MSIAC. The MSIAC is a Department of Defense Information Analysis Center administered by the Defense Technical Information Center and operated by IIT Research Institute under contract number SPO700-99-D-0300. The MSIAC is sponsored by the Defense Modeling and Simulation Office and the Defense Technical Information Center.

Data item number: A004

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
15-12-2000	State of the Art Report	April 2000 – December 2000

4. TITLE AND SUBTITLE
Verification, Validation, and Accreditation (VV&A) Automated Support Tools: A State of the Art Report – Part 1 – Overview

5a. CONTRACT NUMBER
SPO700-99-D-0300

5b. GRANT NUMBER
N/A

5c. PROGRAM ELEMENT NUMBER
N/A

6. AUTHOR(S)
Modeling and Simulation Information Analysis Center

5d. PROJECT NUMBER
N/A

5e. TASK NUMBER
N/A

5f. WORK UNIT NUMBER
N/A

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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Analysis Center
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8. PERFORMING ORGANIZATION REPORT NUMBER
N/A

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

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Suite 500
Alexandria, VA 22311

10. SPONSOR/MONITOR'S ACRONYM(S)
DMSO, DTIC

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
N/A

12. DISTRIBUTION / AVAILABILITY STATEMENT

Distribution Statement A: Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
None.

14. ABSTRACT
This report presents an overview of a project conducted by the Modeling and Simulation Information Analysis Center (MSIAC) to determine the state of the art in automated tools that can be used to support the verification, validation, and accreditation (VV&A) of models and simulations. This paper discusses the background of the project, the need for such tools, the survey methodology and questions, response statistics, and conclusions. Further details are provided in a follow-on report, which is called "Verification, Validation, and Accreditation (VV&A) Automated Support Tools: A State of the Art Report – Part 2 – Details".

15. SUBJECT TERMS
VV&A, Model Analysis, Tools, Modeling and Simulation

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** William Marshall
a. REPORT Unclassified	**b. ABSTRACT** Unclassified	**c. THIS PAGE** Unclassified	SAR	44	**19b. TELEPHONE NUMBER** *(include area code)* 703-933-3344

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

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E.2 The Need for Automated Support Tools

- M&S is vital to the development and operation of military and commercial systems

  Modeling and simulation is assuming an ever-larger role in training, assessment, acquisition, and experimentation for military and commercial systems. The driving forces supporting this trend include the well-understood factors of cost, schedule, logistics, manpower, and environmental impact.

- Investments in M&S are justified only when M&S is credible

  Since models and simulations are approximations of the real world, at best they produce results that are approximations of real world results. These approximations must be justified to assure M&S users that their predictions are credible within the bounds of specific situations, environments, and circumstances. When M&S is proven credible, then decision makers can reap the entire benefits of M&S including cost savings, risk reduction, and schedule acceleration.

- VV&A is the path to proving credibility

  VV&A is a process of applying incremental review, analysis, evaluation, and testing to M&S products for the purpose of improving credibility. This process provides many benefits to the M&S community including enhanced user confidence, improved system performance and reliability, and more predictable and accurate M&S behavior.

- VV&A is too difficult; it costs too much, takes too long, and is too hard to apply

  Current VV&A is perceived as taking too long and costing too much. Program managers view VV&A as a drain on their resources and complain that there is no "tried and true approach" to applying VV&A and that there is no recognized way to know "how much VV&A is enough." VV&A must be made quicker, cheaper, and easier to apply.

- Automated support tools can alleviate some of the difficulties in applying VV&A

  Developing and applying automated support tools can reduce VV&A cost and schedule. The software development community is already taking advantage of this approach. M&S developers are aware of this situation, as the DoD M&S Master Plan notes the need to develop "standardized automated tools to support VV&A" and the SIMVAL99 conference report states that "the VV&A community is not exploiting existing technology as much as desired."

E.3 Analysis of VV&A Automated Support Tools

- There is a great need for automated tools to help reduce the cost, effort, schedule, and risk for VV&A of models and simulations

  The application of automated tools will decrease the cost of VV&A, reduce the effort to conduct VV&A, permit the VV&A schedule to mesh better with the M&S development schedule, produce better VV&A, and produce more credible M&S.

- There are many automated tools that can be applied to VV&A, but these tools are not well known and there are some serious gaps in their coverage

  There is a surprising number of automated tools that can be applied to the VV&A of models and simulations, and more such tools are under development. But there are not nearly enough tools yet nor do they cover all of the community needs. Further, most VV&A and M&S practitioners are unaware of these tools and how to use them.

  For example, there are many M&S verification tools that are based on software CASE tool verification technology. There are excellent requirements tracing tools developed by the software industry that support the full range of VV&A. There are "checkbox tools" that support the accreditation process by automating the required "paper trails."

  There are many *techniques* suitable for supporting M&S validation, but there are not enough *tools* that implement these techniques.

  There are not sufficient automated VV&A support tools that "instrument" M&S exercises analogous to the test and evaluation tools that instrument live exercises.

- The software industry leads the M&S community in the development and application of automated VV&A tools

  The software industry and the Software Engineering Institute's capability maturity model (SEI CMM) have fostered the development of automated tools to ease the verification and validation of software systems. These tools include the code verifiers and requirements trackers commonly applied in M&S. There are additional software industry tools and techniques that have not yet been adopted or adapted for VV&A of M&S.

- The continuing M&S trends towards distributed simulations, high fidelity, and advanced modeling methods increase the difficulties for VV&A

  VV&A automated support tools will need to evolve along with the field of M&S. The trends in M&S towards the increasing use of distributed systems, the march towards high fidelity, and the incorporation of advanced modeling techniques will all exacerbate the need for improved VV&A tools and techniques to support M&S credibility.

  Distributed M&S systems require tools that act across components; VV&A tools that act only on each component in a distributed exercise are not sufficient for understanding the behavior of the system as a whole.

  Successful VV&A for high fidelity distributed simulations will require the development of specialized "simulation instrumentation" tools to assure credibility in assessments, training, and acquisition.

  Advanced modeling techniques such as neural networks and genetic programs used in simulations effectively present "black boxes" to the developer and inhibit understanding of their inner workings. The use of COTS products, inherited objects with encapsulated mechanisms, or components with different security classifications presents similar problems to the conduct of VV&A and the use of automated support tools.

- VV&A of models and simulations is not equivalent to the V&V of software

  There are many fundamental differences between M&S and software systems. One is that M&S is designed to emulate real world system behavior while software is designed to perform functions that are usually not emulations. Another difference is that simulations may need to operate in modes that are not pre-specified so that emerging behavior or responses in unknown regimes can be investigated. Further, the VV&A process for M&S includes verifying and validating the conceptual model, an extra layer of requirements, assumptions, approaches, and algorithms.

E.4 Recommendations for VV&A Automated Support Tools

- The M&S community should develop new automated support tools for VV&A

  The M&S community needs to emphasize developing automated testing tools supporting the validation of distributed simulations, and especially supporting the validation of high fidelity distributed simulations. These tools should be analogues of the automated testing tools used in the testing and evaluation community, and be capable of analyzing all the details of model interactions during simulation runtime.

- The M&S community should monitor V&V tool development within the software industry and be prepared to adopt or adapt these tools to support M&S VV&A

  The M&S community needs to monitor the automated tools developed within the software industry. The software industry already provides many tools used in current VV&A efforts. Software tool providers are well supported in their industry and are continuously developing new automated V&V tools based on current technologies as well as entirely new tools based on developing techniques. These tools can be adapted or adopted to M&S needs as appropriate.

- The M&S community should make more use of visualization tools in support of VV&A

  The M&S community needs to take more advantage of existing visualization tools that already can provide M&S developers and users with a direct means of determining if a system "looks right" and is representing reality correctly. These tools permit deeper understanding of data, results, and system dynamics. Tools such as CAD/CAM viewers, 3D walkthroughs, exercise stealth viewers, and graphing packages for statistical analysis are all directly applicable to VV&A.

- The M&S community should look to develop VV&A tools that help increase the credibility of simulations

  The M&S community needs entirely new types of tools that can directly and quantitatively assure the user that a simulation has sufficient accuracy for decisions over a wide range of situations and input values. New approaches based on control theory, statistical theory, formal methods, software reliability, and intelligent agents should be investigated.

- The M&S community should develop a repository of VV&A tool information

  The M&S community needs to develop a process and a central repository to collect, store, analyze, and disseminate information about automated VV&A tools.

- The M&S community should develop new processes and types of tools that permit feedback of system information

  The M&S community needs to enhance the use of models and simulations in support of the entire system development lifecycle through the concept of simulation based acquisition (SBA). This will require developing new processes and new tools that permit feeding back actual results from system testing and deployment into the core suite of M&S.

1. INTRODUCTION / BACKGROUND

This MSIAC State of the Art Report is the first of two reports that provide a compendium and an analysis of COTS, GOTS, and developmental automated tools that can be applied to the verification, validation, and accreditation (VV&A) of individual models and simulations (M&S) or of systems of models and simulations. This report (Part 1 – Overview) contains an assessment of the breadth of existing tools for VV&A and their applicability, identifies gaps in coverage and/or quality, provides recommendations for the types of tools that will be needed in the future, and presents discussions on special topics that illuminate the needs for these tools. Part 2 – Details contains summary tables and the actual compendium of automated VV&A tools.

1.1 VV&A for Models and Simulations

Modeling and simulation (M&S) is assuming an ever-larger role in training, assessment, acquisition, and experimentation for military and commercial systems. The driving forces supporting this trend include the well-understood factors of cost, schedule, logistics, manpower, and environmental impact. However, to justify the increasing use of M&S in top-level decision making, developers must demonstrate that their products are credible. That is, the M&S community must prove that they can produce correct and defendable results to support their intended users' needs.

Because models and simulations are approximations of the real world, they generate results that are approximations of real world results. These approximations are still useful since good models and simulations simplify and idealize to obtain insights into the systems under consideration. However, the M&S developer must prove that the approximations are reasonable for the decision being supported. The M&S practitioner must assure the users, and they must assure others, that their predictions are applicable within given situations, environments, and circumstances. This is the core of the concept of VV&A: *verification*, *validation*, and *accreditation*.

VV&A is a process of applying incremental review, analysis, evaluation, and testing to M&S products for the purpose of improving credibility. This process provides many benefits for M&S including:

- enhanced user confidence,
- improved performance and reliability,
- more predictable and accurate behavior, and
- reduced program risk.

The Department of Defense has formalized the meanings of verification, validation, and accreditation for their programs. Following the definitions in DoD 5000.59 [Reference A],

- *verification* is the "process of determining that a model implementation accurately represents the developer's conceptual description and specifications."

- *validation* is the "process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model."

- *accreditation* is the "official certification that a model or simulation is acceptable for use for a specific application."

In more common words,

- verification means, "did I build it right?"
- validation means, "did I build the right thing?" and
- accreditation means, "is the thing that is built suitable for my needs?"

All three of these concepts are necessary to support the goal of building and applying credible models and simulations. However, there is much more to successful model building than VV&A. For example, a model could be verified and perfectly valid, but it still may be the wrong tool for the application. Further, although VV&A is necessary for credible models, it may not be sufficient (see the discussions in Chapter 2)!

1.2 The Need for VV&A Tools and this State of the Art Report

Current VV&A is perceived as taking too long and costing too much. Many program managers view VV&A as just another mandated drain on their resources. They complain that there is no "tried and true approach" to applying VV&A, and that there is no recognized way to know "how much VV&A is enough." VV&A practitioners respond that VV&A is the best investment one can make because of the potentially drastic consequences of using incorrect models and simulations. Regardless of any particular program's approach to VV&A, there is a strong need to make it quicker and less expensive.

One method for reducing VV&A cost and schedule is to develop and apply automated support tools. The software development community is already well along on this path. For example, the Software Engineering Institute's Capability Maturity Model (SEI CMM) lists many techniques and approaches that have spurred the development of automated tools. M&S practitioners lag the software community in these developments and should proceed quickly to adapt, adopt, or develop automated tools to answer specific VV&A needs. The DoD M&S Master Plan [Reference A], in sub-objective 5-2 (3), notes the need to develop "standardized automated tools to support VV&A."

Moreover, as noted at the SIMVAL99 conference [Reference B] sponsored by the Military Operations Research Society:

> "It appears that the VV&A community is not exploiting existing technology as much as desired. The reasons for this are manifold. First, M&S management and VV&A practitioners *as a whole* are woefully unaware of existing tools and technologies that could be used to support VV&A. Second, the VV&A community has focused primarily to date on defining terminology and developing methodologies and processes, and has not given adequate attention to the potential benefits of tools and technologies. Other reasons include the lack of a comprehensive survey of tools and technologies available to support the education of the VV&A community or the use of these resources in DoD and elsewhere. No central repository exists to document VV&A tool use or to serve as a resource for future applications of VV&A tools and technologies. Consequently, resources to support VV&A tool use are not identified routinely as part of M&S lifecycle planning. Even when tools are used, their use is often ad hoc and not repeated consistently from M&S project to the next."

VV&A automated support tools will need to evolve together with the field of M&S. There are three important trends in M&S that will exacerbate the need for VV&A tools and techniques to support M&S credibility. These are the increasing use of distributed systems, the goal of higher fidelity, and the incorporation of advanced modeling techniques. Chapter 2 provides discussions of these trends and their effect on VV&A.

The objective of this state of the art report is to alleviate some of the deficiencies cited above by assessing the breadth of existing tools for VV&A and their applicability, identifying gaps in coverage and/or quality, and providing recommendations for the types of tools that will be needed in the future.

1.3 VV&A Background

The fundamental goal of VV&A is to reduce the risk in the use of models and simulations by improving the credibility of M&S results. VV&A increases credibility by applying a process of incremental review, analysis, evaluation, and testing. Sources of model and simulation failure, as recognized by VV&A practitioners, include bad conceptual models, poor design, programming errors, faulty data, and the use of a model outside of its intended domain.

The "V&V" part of VV&A is quite different from the "A" part, in process, performers, and in products. Verification and validation are processes performed primarily by analysts, modelers, and subject matter experts who are knowledgeable in the history of the problem, previous approaches, software development, modeling and simulation technical issues, environments, threat, and special systems. The results of the V&V phase include material used to support the accreditation phase and, ultimately, the accreditation decision. The accreditation decision is made by the accreditation authority, who is often a sponsor or proponent of the system being modeled, but can also be a "mere user." The decision states that a model is, or is not, sufficient for use in the program in particular situations and under specific conditions.

Because of the differences in processes, performer, and products between V&A and accreditation, the M&S community needs different types of automated tools to support separate phases. These differences are discussed within the taxonomy presented in Chapter 3.

1.4 VV&A Master Plans, Guides, and Handbooks

Models and simulations for the Department of Defense are developed in accordance with policies, plans, and guidance codified in various DoD and Service documents. Generally speaking, the DoD and Service M&S *master plans* set the overall policy, *instructions* clarify the policy, and *guides* and *handbooks* indicate how to implement the VV&A policy and incorporate "lessons learned."

The M&S master plans are:

- For DoD: DoD 5000.59-P, Modeling and Simulation (M&S) Master Plan [Reference A]
- For Air Force: Air Force Policy Directive 16-10, Modeling and Simulation Management [Reference F]
- For Navy: Navy Modeling and Simulation Master Plan [Reference G]
- For Army: Army Regulation 5-11, Management of Army Models and Simulations [Reference H]

The VV&A instructions include:

- For DoD: DoD Instruction 5000.61, DoD Modeling and Simulation (M&S) Verification, Validation and Accreditation (VV&A), April 29, 1996 [Reference I]
- For Air Force: Air Force Instruction (ARI) 16-1001: Verification, Validation and Accreditation (VV&A), June 1996 [Reference J]
- For Navy: SECNAV Instruction 5200.40: Verification, Validation, and Accreditation (VV&A) of Models and Simulations, April, 1999 [Reference K]
- For Army: Department of the Army Pamphlet (DA PAM) 5-11: Verification, Validation, and Accreditation of Army Models and Simulations, 15 October 1993 [Reference L]

Guidebooks and implementation handbooks include:

- For DoD: DoD Modeling and Simulation Office (DMSO), Department of Defense Verification, Validation and Accreditation Recommended Practices Guide, November 1996 [Reference M]
- DoD Modeling and Simulation Office (DMSO), Department of Defense Verification, Validation and Accreditation Recommended Practices Guide, 2000 [Reference N]
- For Navy: Department of the Navy Verification, Validation, and Accreditation Implementation Handbook [Reference O]

Another guidebook of interest has been developed by the IEEE for Distributed Interactive Simulation (DIS) [Reference P].

1.3 VV&A Automated Support Tools Taxonomy

This report uses the following taxonomy for classifying VV&A tools and techniques. Definitions and details of the categories are provided in Chapter 3.

- Tool Application (verification, validation, accreditation)
- Sponsor (OSD, Joint, Service, DoD Agency, Government/non-DoD, Academic, Commercial)
- Applicability to Distributed Systems (yes, no)
- Cost (low, medium, high)
- Simulation Phases (planning, requirements, conceptual modeling, design, implementation, etc.)
- Simulation Environments (simulation variety, development environment, software language)
- Simulation Aspects (architecture, data, system/component interfaces, algorithms, etc.)
- Specialized Tool Use Considerations (host computer, disk space/RAM, operating system, network, VV&A status of the tool, etc.)
- Training (training length, training availability)
- Additional Tool Information (software language, classification, distribution limitations, sponsor/owner, developer, etc.)
- Previous Users and Uses (name, organization, phone number, email, use of tool)

1.4 Organization of This State of the Art Report

This state of the art report provides:

in chapter 2, discussions of:
- fundamental differences between M&S and software
- trends that will stress VV&A tools
- visualization
- feedback from system development
- direct quantitative assurance

in chapter 3, a presentation of the VV&A tool taxonomy

in chapter 4, discussions of VV&A techniques for automated tools

in chapter 5, a presentation of the survey form used for developing the compendium of automated VV&A tools in chapter 6, analysis of existing VV&A automated support tools

in chapter 7, discussions of:
- conclusions
- summary of assessments
- recommendations on development for new VV&A tools
- challenges

in the appendix:
- references

2. SPECIAL TOPICS

This chapter presents discussions of special topics that effect the development and application of automated support tools for VV&A. The first special topic provides background on the differences between software (in general) and M&S (in particular) and why special automated support tools for VV&A are required. The second special topic expands the discussion on the current trends in M&S development and indicates the ways VV&A support tools must evolve along with M&S. The third special topic shows some of the many ways that visualization tools can be applied to support VV&A of simulations. The fourth special topic discusses the need to develop VV&A tools and processes that enable feedback of actual system results into the supporting modeling and simulation, especially in support of simulation based acquisition. The fifth special topic presents the need for new VV&A tools and processes that extend current capabilities towards a goal of supplying direct quantitative assurance in the results of models and simulations.

2.1 Fundamental Differences between Software and M&S, and the Need for Tailored M&S VV&A Tools

The development of models and simulations to represent a system almost always includes extensive development of software. The software community is more experienced and mature than the M&S development community, and this maturity is evidenced in the wealth of automated tools available to support software development. Although the M&S community has adapted many of these tools for the VV&A process, they are not sufficient for all of the needs. This is a consequence of some fundamental differences between M&S and software, differences that force adaptation or development of specialized tools.

One basic difference between M&S and a software development in general is that there is a "target" system in M&S. That is, models and simulations are designed to emulate the real world (or potential) behavior of an existing (or future) system. The degree to which the M&S behavior matches that of the target system (which could be software itself) is of primary importance. Many of the requirements for the simulation are derived directly from this need to represent system behavior. However, software in general does not have real-world systems to emulate. Software is also designed from requirements, but these requirements do not usually specify a function representing an existing system or humans to any given degree of fidelity. Thus, the M&S community needs specialized VV&A tools to determine the fidelity of the results of a simulation relative to the properties of the target system.

A second difference between M&S and a software development in general is that M&S incorporates an extra step for the development of the M&S conceptual model. This conceptual model contains assumptions, approaches, and algorithms, and acts as an intermediate layer that codifies the developer's concept about the simulation and how specific objects/entities/federates should perform. The conceptual model layer helps transform simulation requirements into simulation specifications. It consists of three parts, simulation context, simulation elements, and simulation concept. The simulation context contains information about the simulation's domain, that is the situation under consideration in the simulation. The simulation concept describes the idea or use for the simulation. The simulation element provides concepts for the simulation's components and the corresponding assumptions, algorithms, data, and relationships. Conceptual models permit better understanding of simulation requirements and can lead to more accurate code. However, conceptual models place additional tasking on the developer to assure that the conceptual model itself is correct. Consequently there is a need for automated VV&A tools for verifying and validating the conceptual model.

A third difference between M&S and software development in general is involved with the application of M&S. Simulations can be (and often are) used to explore the unknown by forecasting system behavior in denied operating areas, hostile environments, and future scenarios, or by attempting to emulate emerging behaviors. In these cases, M&S is used to extrapolate from known situations to unknown situations. This is usually not the case in software systems where we wish to avoid unknown regions and actually force the software system to halt if it encounters such inputs or states. Consequently, the V&V of software systems deals with requirements that are more static since software should have a well-defined situation to operate in and well-defined behaviors. VV&A tools for M&S, however, must deal with requirements and operations in unknown (dynamic) regimes and with situations that are unpredicted.

This fourth difference, closely related to the difference immediately above, calls into question the whole concept of VV&A for predictive models and simulations. For M&S that extrapolates from known situations to the unknown, it may be impossible to perform "validation" because there may be no results that represent "reality" in these cases. Similarly, how can automated tools help validate predictions, especially for "far future" systems? In this case, we can use, at best, tools supporting "face" validation where subject matter experts review the results of the simulation and declare that they at least look like they might be reasonable. In this situation, there are also problems validating the conceptual model since the requirements and assumptions may not be reasonable and, in fact, might be indicated as being unreasonable by the outcome of the simulation.

2.2 Trends That Will Stress VV&A Tools

The field of M&S is evolving rapidly, and VV&A tools must evolve alongside. Three ongoing trends in M&S are the use of distributed systems, the march towards "high fidelity," and the incorporation of advanced modeling techniques. All of these trends are straining the ability of existing VV&A tools and techniques to provide assurance.

Distributed systems allow developers to build large simulations from the "best available" components located anywhere in the world. Reusing components can reduce cost, risk, and schedule. Just like VV&A for monolithic simulations, VV&A for distributed simulations must be concerned with the immense amounts of details produced and consumed in the process of creating an accurate representation of a system. However, VV&A for distributed simulations must also check all the details that are interchanged between the separate models since a basic fact of VV&A life is that even if each component model is correct, there is absolutely no guarantee that the distributed simulation composed of these components acting together accurately represents reality! Consequently, automated VV&A tools must evolve beyond thoroughly understanding each part in a system, and support the understanding of the behavior of the system as a whole. The tools must support investigating issues relating to the crucial interactions of models over a network, interactions that cannot easily be evaluated with any existing tools. This requires VV&A tools that work directly on the distributed simulation *infrastructure*.

"High-fidelity" simulations are highly accurate, detailed simulations like those that have been applied for many years to predictive engineering of new systems, or to engineering improvements to existing systems. These simulations include high-fidelity representations of the design-level actions and interactions that determine a system's real-life performance. They are being applied to training in more representative situations; analyzing, planning and rehearsing realistically; and making defendable decisions supporting the acquisition process. For high fidelity distributed simulations, the VV&A tool issue involves conceptual model errors and the accuracy of a distributed system as affected by latency in data interchange, update rates, fidelity mismatch, and spatial, environmental, and temporal mismatch. These issues have always been present in distributed simulations, but have not been the accuracy drivers until the advent of higher fidelity.

Advanced modeling techniques such as genetic algorithms, intelligent agents, and neural networks provide methods to optimize systems and represent behaviors that are less tractable to conventional approaches. These techniques support the applications of simulations for representing emergent behavior, learning behavior, and unknown situations (see section 2.1, "third difference" above). From the perspective of developing VV&A tools, these advanced techniques all generate components that present virtual "black boxes" and prevent detailed inspection. Their internal assumptions and algorithms may not be "scripted" in the same way as classical, deterministic models. Also, there may be no way to track software code to requirements and track operations to assumptions. Specialized VV&A tools will have to be developed that can handle these advanced modeling approaches.

To a certain extent, VV&A tools also must operate on black boxes for M&S components represented by commercial of the shelf software (COTS), by objects and their encapsulated mechanisms in object-oriented software systems, and by software code that is classified to higher levels than the rest of the simulation.

2.3 Visualization Tools for VV&A

Visualization of data, results, and system dynamics is a powerful, but underutilized, approach for the VV&A of models and simulations. There are a number of existing visualization tools which are directly applicable to the problem at hand, ranging from presentation graphics for results, to graphing tools for statistical analysis, to three dimensional viewers for engineering drawings (CAD/CAM rendering), to exercise stealth viewers (magic carpets).

For verification and validation, visualization tools can be used to check if a system is performing to requirements, and if not, can be used to determine the type of error that is occurring. For example, visualization tools can be used to "trace back" through the code and requirements to determine if an error is caused by:

- an piece of software code incorrectly coded against a set of specified requirements (verification error),
- an error in the conceptual model (validation error in conceptual model), or
- an error in the requirements themselves (validation error in requirements).

Visualization tools can also help an analyst or subject matter expert determine if a system "looks right" and is representing reality correctly. Visualization tools can be applied during an exercise playback to discover the exact time or the exact event (or series of events) at which a simulation anomaly first occurs (the initial diversion from reality).

For accreditation, visualization tools can help "make the case" to the accreditation authority that the simulation is, in fact, a reasonable representation of reality within certain bounds.

Visualization tools support the VV&A of M&S in all three functional areas: training, analysis, and acquisition. Visualization tools are a natural fit with training M&S. In fact, the primary interface for the users of a training system is a visualization of the virtual environment that permits interaction with the humans-in-the-loop. These tools are used in the V&V of a training system to determine training goodness and are also one means of "instrumenting the range" to check if interactions are correct in distributed simulations. Visualization tools are a primary debugging and presentation method for M&S used in analysis. The behaviors of systems (such as tactical responses) can be visualized and checked to see if they correspond correctly with the requirements. For acquisition, visual tools are used in the engineering development process and in statistical tests for better understanding of the basic development outcomes.

2.4 VV&A Tools Supporting Feedback From System Development

As models and simulations are being applied to support the entire system development lifecycle through the concept of simulation based acquisition (SBA), the M&S community now has the opportunity to "fine-tune" models over a long period of time.

For example, models that are used to predict performance of a future system can be upgraded to correspond with actual results as system testing and deployment take place.

Currently, most simulations are not maintained under strict configuration management for long periods of time, especially when compared to the lifetimes of the systems they are modeling. For example, the development time for a major Navy surface combatant may be more than a decade, and the service life of the system can approach half a century. Models that are more than five years old have likely been revised many times and not kept under configuration control; in addition, the hardware platforms needed to run the models may have become obsolete and unavailable. As a consequence, as real systems are developed new M&S is developed in step and the results of previous versions are often lost or buried. Similarly, brand new simulations are developed for brand new systems regardless of the possible similarity to existing systems.

However, SBA presents a clear opportunity to upgrade and improve a simulation to represent more closely the target system. Along with this, VV&A should develop new processes and new tools that enhance the feedback of actual results as the systems being modeled are built. This issue is a part of the overall problem of how to get M&S "lessons learned" understood and disseminated into the M&S community at large for use on future developments. Automated tools could support this process.

2.5 VV&A Tools for Direct Quantitative Assurance

The culmination of the traditional VV&A process is the accreditation decision stating that the M&S is "good enough" for the purpose at hand. That is, for certain situations, for specific systems, users, environments, *et al*., the simulation is sufficient for the given application. This accreditation decision is based on a number of factors, some quantitative, but mostly qualitative and subjective. A valuable extension of the current VV&A process would have the goal of providing direct quantitative *assurance* in results from simulations of large, complex systems or systems of systems. Here, assurance would be defined as a combination of confidence, reliability, and quality. Measuring assurance quantitatively would reduce risk tremendously and lead to wide acceptance of M&S across a number of fields.

M&S developers and theoreticians should examine approaches, adapt methodologies, and develop measures to produce direct approaches of quantifying and visualizing assurance in models and simulations. A part of this process would be a review of the theoretical foundations of simulation science to further the development of the rigor needed for building measures of assurance. Also, as in any simulation development, the process will need to produce methods to obtain good estimates of measures, and methods to obtain good estimates of the goodness of these estimates. Certainly, many of the concepts have already been developed within VV&A, but other fields could also offer possible approaches and methodologies.

Possible approaches to providing direct quantitative assurance can be found in control theory utilizing the concept of stabilization for devices under safety control, and in the application of feedback loops. Another approach can be based on the structured, quantitative approach for predicting complex system performance under development at the Los Alamos National Laboratory [Reference C]. Other methods could be adapted from those developed by the Ballistic Missile Defense Organization (BMDO), the National Institute of Standards and Technology (NIST), and the Software Engineering Institute (SEI). The applications of formal methods and reliability theory (including fault tree analysis) should also be investigated.

3. TAXONOMY OF VV&A AUTOMATED SUPPORT TOOLS

This chapter presents a taxonomy for VV&A tools. There are many possible ways to organize VV&A automated support tools, but by specifying a single taxonomy, comparisons and analysis can proceed in an orderly fashion. The taxonomy used in this report is based on that used for the SIMVAL 99 M&S V&V Tool Survey (see Reference B) but modified with the addition of top-level categories for application (verification, validation, or accreditation), sponsor, applicability to distributed systems, and cost. These are followed by the SIMVAL 99 categories for the simulation *phases* for which the tools are applicable, the simulation *environments* for which the tools are applicable, and the simulation *aspects* for which the tools are applicable. These categories are all described below.

3.1 Tool Applications

The basic functions of VV&A that need to be supported by automated tools include establishing the validity of M&S conceptual models (i.e., basic assumptions, premises, and algorithms); tracing the validated M&S requirements throughout the M&S lifecycle process; testing the software code for errors; monitoring the M&S developmental and maintenance errors and software change reports; reviewing and evaluating M&S user documentation and support services; establishing the validity of M&S input data and corresponding output data; documenting VV&A plans and reports; filing documentation with appropriate authorities; and testing the M&S outputs against known values.

Organized by the top-level category in the VV&A tool taxonomy, these functions are:

- verification (requirements tracing, M&S input/output verifying, software internal error checking)
- validation (conceptual model validating, M&S input/output data validating, automated testing)
- accreditation (M&S and VV&A documenting, automated VV&A reporting/filing)

Many tools will support two or three of these functions.

M&S verification tools are mostly based on software verification tools, although there are fundamental differences between M&S and software systems in general (see section 1.5). CASE tools are a good example. Visualization tools can also be useful in verification. The current trend towards component-based M&S development both supports and complicates effective and affordable M&S verification. Verification is made easier by reusing code that has already been verified and/or validated in specific circumstances. Verification is made more difficult because of the relative immaturity of automated tools supporting the integration of modules and the testing of interactions between modules.

M&S validation tools include systems engineering tools for developing validation criteria; CASE tools for validating the conceptual model; database management systems for validating the input data; and statistical, mathematical, and visualization tools for validating the M&S application.

M&S accreditation tools include database management systems for ensuring that the proper requirements and testing trails are maintained and presented to the accreditation authority for decisions.

3.2 Sponsor

The sponsor is the government (or non-government) organization which has specified the requirements or paid for an M&S program and the accompanying VV&A. Identifying the sponsor is important because a VV&A practitioner often chooses to use tools developed or in use by his sponsor. Alternatively, the practitioner will sometimes want to know what tools are being used to support VV&A "elsewhere."

The basic categories for sponsor in this report are:

- OSD
- Joint
- Service
    - Army
    - Navy
    - Air Force
    - Marine Corps
- DoD Agency
- Government/Non-DoD
- Academic
- Commercial

Many tools may have been developed by one sponsor, but are used by many sponsors.

3.3 Applicability to Distributed Systems

As noted in the introduction, and as discussed more completely in the section 5.3, an ongoing trend in M&S development is the move towards distributed systems. The VV&A of distributed systems is a special art of its own, and the need for tools to support the VV&A of distributed systems is critical. This part of the taxonomy indicates whether a tool is designed for application in a distributed simulation.

3.4 Cost

The cost of a tool can determine whether it can practicably be applied in support of a given VV&A effort. This part of the taxonomy attempts to determine whether a tool is

- low cost (less than $1000)
- medium cost ($1000 to $5000)
- high cost (greater than $5000).

These costs are the initial purchase (or leasing) costs and do not include expenditures for training, maintenance, or annual licenses.

3.5 Simulation Phases

There are many phases in the development of a modeling and simulation effort. All of these require support by automated VV&A tools. Following the categories used in SIMVAL 99, the simulation phases considered here are:

- planning
- requirements
- conceptual modeling
- design
- implementation
- testing and integration (unit, function, sub-system, system)
- configuration management
- use/application and maintenance
- assessment/evaluation
- interoperability/compatibility
- modification
- V&V planning
- V&V documentation/reporting
- V&V management
- accreditation/certification
- standards compliance.

3.6 Simulation Environments

The simulation environment includes the type of simulation, how it is developed, and the software language. Following the categories used in SIMVAL 99, the simulation environments considered here are:

- simulation variety
  - closed form
  - continuous
  - discrete event
  - real-time
  - human/system/hardware-in-loop
  - distributed processing
  - distributed simulation
- development environment
  - structured
  - object-oriented
  - formal system
  - “waterfall”
  - evolutionary/spiral
  - rapid prototyping
- software language(s) which the tool accommodates.

3.7 Simulation Aspects

The simulation aspects are additional features to the simulation which influence the type of VV&A tools required. Following the categories used in SIMVAL 99, the simulation aspects considered here are:

- architecture
- data (collection, reduction)
- system/component interfaces
- human interfaces (e.g., GUIs)
- algorithms
- behaviors
- prototypes
- management
- test planning/execution
- results evaluation.

3.8 Specialized Tool Use Considerations

Automated VV&A tools require specified hardware/software/network environments to run effectively. This category of the taxonomy indicates some of these factors dealing with tool use. They are:

- host computer(s) required
- disk space/RAM required

- operating system(s) required
- network(s) required
- special configurations required
- application software required
- VV&A status of the tool

We emphasize the last of these factors, namely whether the automated tool has undergone any VV&A of its own!

3.9 Training

This category of the tool taxonomy deals with the training necessary for a VV&A practitioner to become effective in a tool's use. The factors are

- training length
- training availability (locations)

3.10 Additional Tool Information

This category of the taxonomy provides additional descriptive information concerning the VV&A tool. Some of the factors are included in previous categories, but without the specificity allowed here. The factors are:

- software language(s) used
- classification level
- distribution limitations
- sponsor/owner
- developer
  - organization
  - point of contact
  - address
  - phone number
  - email
- distribution point of contact
  - name
  - title
  - organization
  - address
  - phone number
  - email

3.11 Previous Users and Uses

This final category in the taxonomy covers previous applications of the tools in support of VV&A efforts. The factors are:

- name
- organization
- phone number
- email
- previous use of tool

4. VV&A Tool Techniques

This chapter presents a discussion of some specific techniques used by VV&A tools. We will follow the nomenclature of the software industry and note that the tools are used for:

- static analysis,
- dynamic analysis, or
- formal analysis.

Static tools directly analyze the form and structure of a system without executing the product. Example techniques include audits, reviews, inspections, and data flow analyses. Static tools are usually used to verify software requirements and design. They are also used to inspect the developed source code and trace software requirements. Specific examples include:

- static analysis and design tools supporting conceptual model validation and requirements tracking,
- requirements tracing tools supporting requirements tracking,
- configuration management tools supporting requirements tracking, M&S and VV&A documenting, and automated VV&A reporting/filing,
- software metric tools supporting software internal error checking, and
- group support systems supporting conceptual model validating and M&S and VV&A documenting.

Dynamic tools directly analyze the response of a system to inputs by executing or simulating that system. The main examples are testing, prototyping in support of checking software requirements, and visualization. Specific examples include:

- mathematical and statistical tools supporting M&S input/output validating and automated testing,
- instrumenters, dynamic analyzers, and automated testing tools supporting software internal error checking and automated testing, and
- visualization tools supporting verification and validation of requirements, conceptual models, and software codes.

Formal analysis tools analyze the algorithms of a system using mathematical techniques to prove the correctness of an approach. Specific examples include:

- algorithm analysis tools supporting M&S verification,
- proof of correctness tools supporting M&S verification, and
- symbolic execution tools supporting M&S verification.

Additional details can be found in Reference D.

The techniques are listed below in alphabetical order.

Algorithm Analysis Tools (Formal Analysis)

Algorithm analysis tools support M&S verification by directly examining the logic and accuracy of software requirements. The formal process of translating algorithms into a structured format also involves rederiving equations or evaluating the suitability of specific numerical techniques. The technique checks that algorithms are correct, appropriate, stable, and meet all accuracy, timing, and sizing requirements. Algorithm analysis also examines the correctness of the equations and numerical techniques.

Configuration Management Tools (Static Analysis)

Configuration management (CM) tools support M&S verification and accreditation by performing requirements tracking and VV&A documenting, and by automating the reporting and filing of VV&A information. CM is used to manage the evolution of M&S hardware and software during the entire system lifecycle. CM tracks the configuration of the system (including requirements, software, hardware, and networks) over time and systematically controls changes to the configuration.

Group Support Systems (Static Analysis)

Group support systems (GSS) support M&S validation by coordinating information exchange during meeting and reviews. GSS are especially useful for collecting comments and critiques of models from subject matter experts. Information collected by GSS help refines model design, basic assumptions, and underlying theories and is also useful during design and code reviews.

Instrumenters, Dynamic Analyzers, and Automated Testing Tools (Dynamic Analysis)

Instrumenters, dynamic analyzers, and automated testing support verification by ensuring that M&S execute without detectable runtime errors. These tools insert software "probes" into code to track performance and search for runtime errors. They work dynamically while the code runs. Detecting runtime errors can be difficult since they often occur intermittently during M&S execution. Automated test coverage analyzers are tools used to examine if a simulation encounters all the conditions to which it is sensitive. Performance analysis tools are employed to optimize the performance and usability of software by locating performance bottlenecks and reporting application and component performance.

Mathematical and Statistical Tools (Dynamic Analysis)

Mathematical and statistical tools support validation by providing mathematical, statistics, and engineering analysis by determining the degree of compliance to system specifications. These tools are necessary because even if a simulation has had its design verified, its requirements traced, and its configuration maintained properly, it could still fail system specifications. These tools are used to understand how closely the output of a model matches real world data. Examples include general-purpose statistical packages, specialized statistical packages, mathematics packages, and spreadsheets. Visualization packages are often considered in this class, but are so important to VV&A that they are separated into their own category in this report.

Proof of Correctness Tools (Formal Analysis)

Proof of correctness tools support M&S verification by employing theoretical and mathematical models to prove that the program is correct. This formal analysis technique first takes a software code and attempts to represent it as a formal mathematical theorem. The technique next uses first-order predicate calculus to prove the mathematical theorem. The result is a formal proof of the correctness of the program. This, and other formal analysis techniques, can form a major part in the development of direct, quantitative measures of M&S assurance.

Requirements Tracing Tools (Static Analysis)

Requirements tracing tools support verification by tracking requirements throughout the M&S development cycle. These tools can track the life of software and hardware M&S requirements in both forward and backward directions; they can account for requirements as they evolve (derived requirements) during system development; they can “link” test plans data to requirements; and they can “link” requirements to documents.

Software Metric Tools (Static Analysis)

Software metric tools support verification of M&S software design by identifying the life cycle cost and the likelihood of undetected errors in code. Software quality measures are tailored to software analysis, design, and code. Software development cost measures use function points. These tools are all useful for estimating and managing software development. The IEEE [Reference E] has developed an extensive list of software metrics.

Static Analysis and Design Tools (Static Analysis)

Static analysis and design tools support conceptual model validation and requirements tracking by establishing programming standards and naming conventions, and by maintaining the integrity of data passed software components. Most of these tools are computer aided software engineering (CASE) tools. These CASE tools have reached a high level of maturity in their development by the software industry. They promote careful code development when used with requirement tracking tools. They are also used to "reverse engineer" a legacy simulation code to recover design information. CASE tools are directly applicable to M&S development and, in fact, provide the basis of most VV&A toolkits. However, they do not encompass all of the functions that must be performed in simulation VV&A.

Symbolic Execution Tools (Formal Analysis)

Symbolic execution tools support M&S verification by verifying that the relationship between the software requirements specification and the source code is formally correct. These tools work by executing the program using symbolic values instead of numerical data. The program's algorithms then produce output represented as a combination of logical and mathematical expressions in terms of the symbolic values. This output can be examined directly to determine formal correctness of the code.

Visualization Tools (Dynamic Analysis)

Visualization tools support M&S verification and validation by graphically depicting the results of simulation execution. They help simulation developers and users determine that a system "looks right" and is representing reality correctly through enhanced understanding of data, results, and system dynamics. These tools include CAD/CAM viewers, exercise stealth viewers, graphs for output presentation, and graphing packages for statistical analysis. For verification, these tools are used to check if a system is performing to requirements. For validation, these tools show that the system "looks right" in its operation. For accreditation, visualization tools can help "make the case" to the accreditation authority that the simulation reasonably represents reality.

5. SURVEY FORM FOR VV&A AUTOMATED SUPPORT TOOLS

Tool Name:

Brief description of the tool, its primary use(s), and the issues it addresses:

Application (please check all that apply):

- ☐ Verification
- ☐ Validation
- ☐ Accreditation

Sponsor:

- ☐ OSD
- ☐ Joint
- ☐ Service
  - ☐ Army
  - ☐ Navy
  - ☐ Air Force
  - ☐ Marine Corps
- ☐ DoD Agency
- ☐ Government / Non-DoD
- ☐ Academic
- ☐ Commercial

Is the tool applicable to distributed systems?

- ☐ Yes
- ☐ No

What is the cost of the tool?

Simulation **phases** for which the tool is applicable (please check all that apply):

- ☐ M&S Planning (including resource estimation)
- ☐ M&S Requirements
- ☐ M&S Conceptual Modeling
- ☐ M&S Design
- ☐ M&S Implementation
- ☐ M&S Testing and Integration:
  - ☐ Unit
  - ☐ Function
  - ☐ Sub-system
  - ☐ System
- ☐ M&S Configuration Management
- ☐ M&S Use/Application and Maintenance
- ☐ M&S Assessment / Evaluation
- ☐ M&S Interoperability / Compatibility
- ☐ M&S Modification
- ☐ V&V Planning (including resource estimation)
- ☐ V&V Documentation / Reporting
- ☐ V&V Management
- ☐ Accreditation / Certification
- ☐ Standards Compliance
- ☐ Other (specify)

Simulation **environments** for which the tool is applicable (please check all that apply):

Simulation Type:

- ☐ Closed Form
- ☐ Continuous
- ☐ Discrete Event
- ☐ Real-Time
- ☐ Human / System / Hardware-in-Loop
- ☐ Distributed Processing
- ☐ Distributed Simulation
- ☐ Other (specify)

Development Environment:

- ☐ Structured
- ☐ Object-Oriented
- ☐ Formal System
- ☐ Waterfall
- ☐ Evolutionary / Spiral
- ☐ Rapid Prototyping
- ☐ Other (specify)

Software language(s) which the tool accommodates:

Simulation **aspects** for which the tool is applicable (please check all that apply):

- ☐ Architecture
- ☐ Data:
  - ☐ Collection
  - ☐ Reduction
- ☐ System / Component Interfaces
- ☐ Human Interfaces (e.g., GUIs)
- ☐ Algorithms
- ☐ Behaviors
- ☐ Prototypes
- ☐ Management
- ☐ Test Planning / Execution
- ☐ Results Evaluation
- ☐ Other (specify)

Tool Use Considerations:

Host Computer(s)

Disk Space / RAM Required

Operating System(s)

Network(s)

Special Configurations

Required Application Software

VV&A Status of the Tool

What training is required for personnel to use the tool?

Length

Where Available

Additional Tool Information:

Language(s) Used

Classification level

Distribution limitations

Sponsor / Owner

Developer (organization, point of contact, address, phone number, email)

Distribution Point of Contact (name, title, organization, address, phone number, email)

Previous Users and Uses:

Name	Organization	Phone number	Email	Use of Tool

Other information about the tool (references describing it, methods/metric employed, any special relationship between this tool and CASE tools or other software development/testing automation, etc.)

Other comments?

6. ANALYSIS OF VV&A AUTOMATED SUPPORT TOOLS

This section provides an analysis of the current state of the art of VV&A automated support tools. The analysis is divided into five parts corresponding to:

- an overall assessment of tools,
- an assessment of specific types of tools,
- a discussion of tools for distributed simulations and for *high fidelity* distributed simulations,
- a set of recommendations, and
- challenges.

6.1 Overall Assessment

There is a great need for automated tools to help reduce the cost, effort, schedule, and risk for VV&A of models and simulations.

There are a surprising number of automated tools that can be applied to the VV&A of models and simulations and more such tools are under development. But there are not nearly enough tools yet nor do they cover all of the community needs. Further, most VV&A and M&S practitioners are unaware of these tools or how to use them.

There is no central repository in the M&S community to store and disseminate information about automated VV&A tools.

The software industry is well ahead of the M&S community in the development and application of automated VV&A tools. The software industry and the Software Engineering Institute's capability maturity model (SEI's CMM) have fostered the development of automated tools to ease the verification and validation of software systems. These tools include the code verifiers and requirements trackers commonly applied in M&S.

Component-based M&S development (similar to that in the software industry) could allow more effective and affordable M&S verification.

Advanced modeling techniques may represent model components as black boxes not easily subject to the usual VV&A scrutiny; these representations include neural networks, genetic programs, and commercial of the shelf software.

The ability to VV&A a simulation with reasonable cost, schedule, and risk is going to get more difficult as the community continues adapting distributed simulations, high fidelity simulations, and advanced modeling techniques.

M&S developers need to develop processes and tools to provide feedback from actual system development into the VV&A of simulations, especially as the concept of simulation based acquisition reaches fruition. If simulations are to support the entire acquisition lifecycle, then they must be able to incorporate the results from test and deployments as the actual systems are built. This is especially important for analysis simulations used to predict system performance.

6.2 Specific Assessments

There are many M&S verification tools that rely on software verification technology and CASE tools. There are many excellent requirements tracing tools also borrowed from the software industry that support the full range of VV&A. There are some "checkbox tools" that support the accreditation process by automating the required "paper trails."

There are many *techniques* suitable for supporting M&S validation, but there are not many *tools* that implement these techniques. There are not sufficient automated VV&A support tools that "instrument" M&S analogous to test and evaluation tools used in live exercises.

VV&A practitioners need to incorporate more visualization tools into their "bag of tricks" to support verification and validation. These tools, ranging from graphing packages to engineering drawing viewers to exercise stealth viewers, can all help in the understanding of the correctness of models and simulations.

6.3 Distributed Simulations and High Fidelity Distributed Simulations

VV&A automated support tools will need to evolve as the field of M&S changes. Component-based M&S development (similar to that in the software industry) could allow more effective and affordable M&S verification. However, the trends in M&S toward the increasing use of distributed systems, the march towards "high fidelity," and the incorporation of advanced modeling techniques will all exacerbate the need for VV&A tools and techniques to support M&S credibility. The VV&A of parallel discrete event simulations shares many of the same problems as the VV&A of distributed simulations. Advanced modeling techniques may represent model components as black boxes not easily subject to the usual VV&A scrutiny; these representations include neural networks, genetic programs, and commercial of the shelf software.

VV&A tools that act only on each component in a distributed M&S exercise are not sufficient for understanding the behavior of the system as a whole. New tools should accept the outputs of the traditional VV&A of individual components within the context of a larger system – the high fidelity distributed simulation exercise. The accuracy of each component model is now just an input to the overall exercise error budget.

Successful VV&A for high fidelity distributed simulations will require the development of specialized "simulation instrumentation" tools to assure credibility in assessments, training, and acquisition. New tools should support an analysis of simulation system errors caused by "distribution/network" factors such as latency, slow update rates, lost transmissions, fidelity mismatch, etc. These errors are always present in distributed simulation exercises, but may not be significant until the decisions require high fidelity results. By monitoring and controlling an exercise in real time, the tools should aid answering the following questions related to the data interchanged between model components:

- Is the data flow correct?
- Is the information content within the data packets correct?
- Is the information content appropriate?
- Is the information content having an effect?
- Is the high fidelity distributed simulation exercise producing the interactions and data required for analyzing the problems necessitating the exercise in the first place?
- Is the high fidelity distributed simulation exercise producing the data for calculating the measures (MOEs, MOPs) which will display information useful to the customer?

6.4 Recommendations

The M&S community should emphasize developing new automated testing tools to support effective VV&A. There is a special need for tools supporting the verification and validation of distributed simulations and even more so for high fidelity distributed simulations. These tools should be analogues of the automated testing tools used in the testing and evaluation community, and analyze all the details of model interactions during exercise runtime.

The M&S community should borrow or adapt tools from the software industry to support verification and validation as possible. The software industry provides many tools already used frequently in VV&A efforts. Software tool providers are well supported in their industry and are developing new tools based on current technologies as well as entirely new approaches to verifying and validating software code. These developments should be monitored for potential applications to M&S.

The M&S community should look to develop new approaches and automated tools that increase the credibility of simulations by providing a quantitative measure of assurance that the results of a simulation exercise are within a given accuracy over a specified range of inputs. New approaches based on control theory, statistical theory, formal methods, software reliability, and intelligent agents should be investigated.

The M&S community should make more use of visualization tools in support of VV&A. Visualization tools help M&S developers and users to determine if a system "looks right" and is representing reality correctly. These tools support understanding of data, results, and system dynamics.

The M&S community needs a central repository to store and disseminate information about automated VV&A tools. The repository should be accessible to all practitioners of VV&A. The tools should be stored using a taxonomy along the lines of that developed and presented earlier in this report.

6.5 Challenges

6.5.1 New Approaches for Assurance

Successful VV&A for high fidelity distributed simulations and simulations applying advanced modeling techniques will require the development of new tools that can assure the user that the simulation has sufficient accuracy for decisions over a wide range of situations and input values. Some possible approaches for developing these new tools include:

- control theory and the concept of device stabilization under safety control and the application of feedback loops.

- statistical theories and Bayesian approaches for understanding the behavior of known, tested systems in known situations as applied to the understanding of simulations used to predict performance in unknown situations (extrapolation).

- software quality and reliability - Many situations are very similar in software and simulation development, especially those relating to the verification aspects of M&S VV&A. Two specific software efforts that are immediately applicable to VV&A tool development are their processes for providing audit trails and their processes for formalized documentation requirements.

- programs in intelligent and distributed engineering design and in intelligent control.

- formal methods for predicting confidence in M&S are analogous to mathematical theories about the situations, constraints, and measures of simulations.

6.5.2 Tools Supporting Feedback From Syste m Development

Successful application of models and simulations to support the entire system development lifecycle through the concept of simulation based acquisition (SBA) will require new processes and new tools permitting the feedback of actual results from system testing and deployment into the core suite of M&S. Currently, the longevity of most simulations is very short when compared to that of the systems they are modeling and very few models last more that a few years under configuration control and with hardware platforms that are compatible with the model software.

The challenge here is to revise the process of VV&A and develop new tools to enhance the ability to feed lessons learned and actual results back into existing M&S.

7. SUMMARY

7.1 General

Modeling and simulation (M&S) is assuming an ever-larger role in training, assessment, acquisition, and experimentation for military and commercial systems. The driving forces supporting this trend include the well-understood factors of cost, schedule, logistics, manpower, environmental impact, and denied operating areas. The M&S practitioner must assure the users, and they must assure others, that their predictions are applicable within given situations, environments, and circumstances. This is the core of the concept of VV&A: *verification*, *validation*, and *accreditation*. VV&A applies incremental review, analysis, evaluation, and testing to M&S products to improve credibility. VV&A provides many benefits including enhanced user confidence, improved performance and reliability, more predictable and accurate behavior, and reduced program risk.

Current VV&A is perceived as taking too long and costing too much. Program managers view VV&A as a drain on their resources and complain that there is no "tried and true approach" to applying VV&A and that there is no recognized way to know "how much VV&A is enough." VV&A practitioners respond that VV&A is the best investment one can make because of the potentially drastic consequences of using incorrect models and simulations. Regardless of any particular program's approach to VV&A, there is a strong need to make it quicker and cheaper.

One clear approach for reducing VV&A cost and schedule is to develop and apply automated support tools. The software development community is already well along on this path. The DoD M&S Master Plan notes the need to develop "standardized automated tools to support VV&A" and the SIMVAL99 report states "it appears that the VV&A community is not exploiting existing technology as much as desired." Automated tools will help reduce the cost of VV&A, reduce the effort to conduct VV&A, allow the VV&A schedule to mesh better with the M&S development schedule, produce better VV&A, and produce more credible M&S.

This report provides a compendium of automated VV&A tools along with an assessment of their capabilities, trends, and gaps. The tools are organized with a taxonomy modified from that presented at SIMVAL99. The top categories are tool application, sponsor, applicability to distributed systems, cost, applicable simulation phases, applicable simulation environments, and applicable simulation aspects.

7.2 Analysis

There are a surprising number of automated tools that can be applied to the VV&A of models and simulations and more such tools are under development. But there are not nearly enough tools yet nor do they cover all of the community needs. Further, most VV&A and M&S practitioners are unaware of these tools or how to use them.

For example, there are many M&S verification tools that rely on software verification technology. There are many excellent requirements tracing tools also borrowed from the software industry that support the full range of VV&A. There are some "checkbox tools" that support the accreditation process by automating the required "paper trails." There are many *techniques* suitable for supporting M&S validation, but there are not many *tools* that implement these techniques. There are not sufficient automated VV&A support tools that "instrument" M&S analogous to test and evaluation tools used in live exercises.

The software industry is well ahead of the M&S community in the development and application of automated VV&A tools. The software industry and the Software Engineering Institute's capability maturity model (SEI's CMM) have fostered the development of automated tools to ease the verification and validation of software systems. These tools include the code verifiers and requirements trackers commonly applied in M&S.

VV&A automated support tools will need to evolve as the field of M&S changes. Component-based M&S development (similar to that in the software industry) could allow more effective and affordable M&S verification. However, the trends in M&S toward the increasing use of distributed systems, the march towards "high fidelity," and the incorporation of advanced modeling techniques will all exacerbate the need for VV&A tools and techniques to support M&S credibility. The VV&A of parallel discrete event simulations shares many of the same problems as the VV&A of distributed simulations. Advanced modeling techniques may represent model components as black boxes not easily subject to the usual VV&A scrutiny; these representations include neural networks, genetic programs, and commercial of the shelf software (COTS). Many of the same problems apply to classified simulations where the classification level of the various components can differ. The lack of appropriate clearances can inhibit examination of all the components.

VV&A tools that act only on each component in a distributed M&S exercise are not sufficient for understanding the behavior of the system as a whole. New tools should accept the outputs of the traditional VV&A of individual components within the context of a larger system – the high fidelity distributed simulation exercise. The accuracy of each component model is now just an input to the overall exercise error budget. Successful VV&A for high fidelity distributed simulations will require the development of specialized "simulation instrumentation" tools to assure credibility in assessments, training, and acquisition. New tools should support an analysis of simulation system errors caused by "distribution/network" factors such as latency, slow update rates, lost transmissions, fidelity mismatch, etc. These errors are always present in distributed simulation exercises, but may not be significant until the decisions require high fidelity results.

7.3 Recommendations

The M&S community should emphasize developing new automated testing tools to support effective VV&A. There is a special need for tools supporting the verification and validation of distributed simulations and even more so for high fidelity distributed simulations. These tools should be analogues of the automated testing tools used in the testing and evaluation community, and analyze all the details of model interactions during exercise runtime.

The M&S community should borrow or adapt tools from the software industry to support verification and validation as possible. The software industry provides many tools already used frequently in VV&A efforts. Software tool providers are well supported in their industry and are developing new tools based on current technologies as well as entirely new approaches to verifying and validating software code. These developments should be monitored for potential applications to M&S.

The M&S community should make more use of visualization tools in support of VV&A. These tools help M&S developers and users to determine if a system "looks right" and is representing reality correctly as well as supporting the understanding of data, results, and system dynamics. Tools such as CAD/CAM viewers, exercise stealth viewers, graphs for output presentation, and graphing packages for statistical analysis are all directly applicable to VV&A.

The M&S community should look to develop new approaches and automated tools that increase the credibility of simulations by providing a quantitative measure of assurance that the results of a simulation exercise are within a given accuracy over a specified range of inputs. New approaches based on control theory, statistical theory, formal methods, software reliability, and intelligent agents should be investigated.

M&S developers need to develop processes and tools to provide feedback from actual system development into the VV&A of simulations, especially as the concept of simulation based acquisition reaches fruition. Simulations that support the entire acquisition lifecycle must be upgradeable to incorporate the results from test and deployments as the actual systems are built. This is especially important for analysis simulations used to predict system performance.

The M&S community needs a central repository to store and disseminate information about automated VV&A tools. The repository should be accessible to all practitioners of VV&A. The tools should be stored using a taxonomy along the lines of that developed and presented earlier in this report.

A. APPENDIX

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