Automated Support Tools for Verification, Validation, and Accreditation

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Abstract

This paper reports the results of a survey of automated support tools for verification, validation, and accreditation of models and simulations. It is based upon a project conducted by the Modeling and Simulation Information Analysis Center (MSIAC). A taxonomy is discussed that forms the basis for the survey and analysis. Some material on the present state-of-the-art of these tools is presented. Recommendations are made for improvements to the collection and dissemination of information regarding automated support tools.

1. Introduction

1.1 Background

This paper for Foundations '02 provides 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 paper is based on a MSIAC-sponsored project. The goal was to provide members of the M&S community a means to leverage existing knowledge and capabilities, avoid duplication of effort in the conduct of VV&A, and enable efficient search and discovery of leading-edge efforts. The intended consumers of this information are those people and organizations directly responsible for the development and application of models and simulations to military operations and systems. However, individuals responsible for any modeling and simulation application may find this information of value.

VV&A is a collection of processes that apply incremental reviews, analyses, evaluations, and tests to M&S products for the purpose of establishing M&S credibility and reducing risk to the user. These processes provide many benefits to the M&S community including enhanced user confidence, improved system performance and reliability, and more predictable and accurate M&S behavior. Under current DoD policy, all models and simulations used within the DoD must undergo VV&A.[1,2,3]

In order to identify the need for automated support tools, we note that:

- M&S is vital to the development and operation of military and commercial systems.
- Investments in M&S are justified only when M&S is credible.
- VV&A is the path to proving credibility.
- VV&A is perceived to be too difficult; it costs too much, takes too long, and is too hard to apply.
- Automated support tools can alleviate some of the difficulties in applying VV&A.

Conclusions resulting from a detailed analysis of the VV&A automated support tools include:

- The M&S and software communities have developed many automated tools that can be used to support the verification and accreditation of models and simulations.
- These tools collectively satisfy many of the current functions for supporting VV&A.
- These tools need wider dissemination and they require proper use.
- No single tool satisfies all of the functions for supporting verification.
- No single tool satisfies all of the functions for supporting accreditation.
- The scope of automated tools that support validation is limited.

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[1] Air Force Instruction (ARI) 16-1001: Verification, Validation and Accreditation (VV&A), http://xoc.hq.af.mil/kb/docs/vva_afi.html, June 1996

[2] Secretary of the Navy Instruction 5200.40: Verification, Validation, and Accreditation (VV&A) of Models and Simulations, http://navmsmo.hq.navy.mil/policy/directives/ April, 1999

[3] Army Regulation 5-11, Management of Army Models and Simulations, August 1, 1997, Chapter 5, Verification, Validation, and Accreditation

1.2 Previous Literature

There have been a number of recent assessments of automated support tools for validation and verification. The first of these was the SIMVAL '99 report[4], which presented a taxonomy for V&V tools, and described several tools. Additional material is provided in the VV&A guides produced by the Department of the Navy[5] and DMSO[6,7]. Several other analyses of these tools have been carried out, including a report describing the use of Computer-Aided Software Engineering tools[8] in VV&A processes, and two MSIAC state-of-the-art reports (SOARs).[9,10]

1.3 Scope of the Paper

This paper presents the results of our survey and analysis of automated support tools. We have confined our discussion to broad categories of tools, rather than attempt comparisons between tools.

In this paper, we:

- define VV&A tools,
- discuss the uses of these tools,
- present our research methodology
- and identify and categorize tools.

At the end of the paper, we present conclusions and recommendations.

2. Topic Overview

2.1 Need for Automated Support Tools

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.

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[4] SIMVAL99: Making VV&A Effective and Affordable, the Simulation Validation Workshop 1999. Military Operations Research Society and the Society for Computer Simulation International, May 12, 1999

[5] Department of the Navy Verification, Validation, and Accreditation Implementation Handbook. November 2000. Draft

[6] DoD Modeling and Simulation Office (DMSO), Department of Defense Verification, Validation and Accreditation Recommended Practices Guide, November 1996

[7] DoD Modeling and Simulation Office (DMSO), Department of Defense Verification, Validation and Accreditation Recommended Practices Guide, 2000, on http://www.msiac.dmso.mil

[8] "The Use Of Computer Aided Software Engineering (Case) Tools To Support Verification & Validation", Illgen Simulation Technologies, Inc., Report No. IST99-R-225, August 31, 1999

[9] **"**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, http://www.msiac.dmso.mil.

[10] **"**Verification, Validation, and Accreditation (VV&A) Automated Support Tools - A State of the Art Report Part 2 – Details." Modeling and Simulation Information Analysis Center (MSIAC), July 13, 2001, http://www.msiac.dmso.mil.

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[11], 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[12] 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.

2.2 Description of Automated Support Tools

For purposes of this report we have defined automated support tools for VV&A to include any computer-based tool used during VV&A or M&S development that:

- expedites the VV&A process,
- increases confidence in the outcome of the VV&A process,
- or reduces cost and/or cost uncertainty of the VV&A process.

Tools used during different phases of VVV&A will have different functions.

Desirable functions for tools supporting verification include, but are not limited to, the ability to:

- define requirements,
- trace requirements,
- document software,
- plan software tests,
- test software,
- analyze software tests,
- perform configuration management,
- create audit trails, and
- distill and present information to accreditation authorities in the appropriate formats.

Desirable functions for tools supporting validation include, but are not limited to, the ability to compare simulation results to real world values in a meaningful manner that provides confidence in the simulation throughout its range of applicability.

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[11] DoD Directive DoD 5000.59-P: Modeling and Simulation (M&S) Master Plan, October 1995, http://www.dmso.mil

[12] SIMVAL99: Making VV&A Effective and Affordable, the Simulation Validation Workshop 1999. Military Operations Research Society and the Society for Computer Simulation International, May 12, 1999

Desirable functions for tools supporting accreditation include, but are not limited to, the ability to:
- identify the information needed,
- determine if this information has been obtained, and
- acquire the information.

Tools may provide either direct or indirect support. Direct support refers to tools that directly assist the VV&A process, while indirect support refers to tools that produce results used within the VV&A process. Most tools are indirect support tools. A tool providing any direct support is considered a direct support tool.

2.3 Research Methodology

For examining automated support tools for VV&A, our approach included:
- producing a taxonomy for describing and defining automated support tools for VV&A,
- developing a tools survey form using the taxonomy as a basis,
- creating a list of "targets" for receiving the survey,
- distributing the survey,
- collecting and analyzing the completed surveys, and
- crafting conclusions.

The taxonomy developed was used as the basis for a survey form. This survey form is reproduced in Appendix A. The survey form was distributed to a wide variety of commercial and government organizations. Several different methods were used to develop survey targets including:
- identifying specific VV&A-focused organizations and points of contact,
- developing a list of other government and commercial organizations that might use VV&A or create automated support tools and points of contact, and
- broadcasting notifications of the survey via several group e-mail lists and e-mail reflectors within the M&S community, including the Simulation Interoperability Standards Organization (SISO) VV&A Forum reflector.

In order to achieve consistency in the report, only a single survey form was used. The authors feel that future surveys would proceed more smoothly if different surveys were prepared for different communities. COTS vendors are normally unfamiliar with DoD-specific acronyms and concepts, and the resultant misunderstandings reduce the response rate and accuracy when the misunderstanding cannot be clarified with additional effort by the survey team.

2.4 Taxonomy

There are many possible ways to organize VV&A automated support tools, but specifying a taxonomy allows 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[13] but modified with the addition of top-level categories for use (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.

To efficiently analyze the returned survey forms and to assess the VV&A automated support tools, the MSIAC developed a new category in the taxonomy, the *tool type*. These types correspond directly to the eight primary functions that seem to categorize the uses of the tools within the M&S community. The eight tool types are as follows:

- *Resources* consisting of websites and repositories that contain references, toolsets, policies, and information that can be valuable to the planners and users of VV&A.
- *Documentation tools* including planning and documentation aids, and software documentation tools.

[13] SIMVAL99: Making VV&A Effective and Affordable, the Simulation Validation Workshop 1999. Military Operations Research Society and the Society for Computer Simulation International, May 12, 1999

- *Development environments* including software development environments, modeling tools and simulation development environments, and federation development tools.
- *Supporting tools* including visualization tools, and mathematics and statistics packages.
- *Verification tools* including requirements management, specification, and tracing tools; automated testing/measurement/debugging tools; simulation testing tools; and coding standards enforcement tools.
- *Configuration management tools* used to monitor, track, and control changes to software.
- *Software costing tools* used to estimate the development costs of software systems, including verification and validation systems.
- *Other tools* including compilation tools, reliability evaluation tools, database checker and design tools, optimizers for simulation inputs, floating point error analysis tools, software analysis tools, and error collection and analysis tools.

Supporting tables for the analysis presented below are contained in Appendix B.

2.5 General Analysis

Of the tools reviewed, there are:
- 41 tools that directly support verification,
- 6 tools that directly support validation, and
- 5 tools that directly support accreditation.

The remaining tools indirectly support verification, validation, or accreditation.

Sponsorship of the surveyed tools can be characterized as follows:
- all of the tools that directly support validation are sponsored by the government.
- all of the tools that directly support accreditation are sponsored by the government.
- most of the tools that directly support verification are commercial automated testing packages.

Further:
- 6 tools have been sponsored exclusively by military services.
- 11 tools have been sponsored exclusively by other DoD components.
- 12 tools have been sponsored exclusively by non-DoD government organizations.
- The remaining tools have some degree of commercial sponsorship.

Further analysis indicates that:
- The government-sponsored tools are either directed towards specialized aspects of VV&A and/or specialized aspects of software development, or support the government's specialized VV&A process functions.
- The DoD-sponsored tools are VV&A oriented.
- The tools sponsored by other government agencies are oriented towards specialized aspects of software development, although some work has been done in the area of M&S validation.
- The commercial tools are oriented primarily towards general problems of software verification, software configuration management, requirements traceability, database development, and data representation and analysis, although some commercial tools specialized for M&S are available.

The remainder of this section provides detailed assessments of the tools organized by tool type.

2.6 Detailed Analysis

Resources consist of websites and repositories that contain references, toolsets, policies, and information that can be valuable to the planners and users of VV&A. Resources could also include orgainzations, conferences, or conference proceedings if one were to extend the concept beyond automated support tools.

Analysis: Surveys were received for 2 resources of four identified. All tools in this category have been developed with government funding. Some resources are specialized to one model or simulation, and other resources have information pertinent to multiple models. The specialized resources are not based on model-specific concepts and

could be replicated for other models. The resources do not yet provide complete coverage of the information needed for VV&A of all models and simulations, but the technology for these resources has been demonstrated.

Documentation tools include (1) planning and documentation aids, and (2) software documentation tools.

Surveys were received for 6 tools falling in the "documentation" category. An additional 3 documentation tools were identified. All of these can be considered to be primarily "documentation" tools, although they may have some other functions.

Planning and documentation aids assist accreditation authorities or VV&A agents in performing their duties. The tools are used for purposes such as estimating the cost of the effort, determining what information is required for accreditation, and preparing reports in a specific format.

Analysis: Surveys were received for 5 planning/documentation aids out of 5 identified. All of these tools have been developed with government support. These tools are perhaps the most significant tools and the tools of most general interest in this report. Different tools handle different parts of the VV&A process. These tools are not completely mature yet, but are rapidly approaching maturity and appear to be very promising. It is anticipated that modifications will occur as these tools are used in M&S programs as part of an integrated process. Once these tools win acceptance, a program to integrate tools that support various aspects of the VV&A process (possibly including commercial tools) would be beneficial.

Software documentation tools are commercially developed tools that automate the process of preparing documentation, thereby reducing its cost and/or improving its quality. Quality software documentation supports accreditation by providing useful information to the accreditation agent about the function of the software. The software documentation tools surveyed are all available as COTS.

Analysis: A survey was received for 1 software documentation tool out of 4 identified. These tools appear to provide automatic documentation capability for software written in common languages such as C++, FORTRAN, and Ada. As with all CASE tools, the users must select tools relevant to their projects and development environments, since all tools are not suitable for every situation.

Development environments include (1) software development environments, (2) modeling tools and simulation development environments, and (3) federation development tools. Surveys were received for 6 tools falling in the "development environments" category. A total of 25 development environments were identified. These environments may also provide some other functions.

Software development environments increase the productivity of a software developer or team of developers. These products support production of standardized bug-free software, distributed applications, and reuse of proven software modules. They can expedite the verification of software by improving the quality of submitted software. These tools are intended for general purpose software development and are not specialized to modeling and simulation. In general, they would not provide assistance with conceptual model development. All tools discussed are available COTS.

Analysis: Surveys were received for 3 software development environments out of 12 identified. The software development environments appear to be useful in promoting collaborative software development and in promoting reuse of previously verified portions of software. Some government funding has been used for special purpose environments. Some development environments are intended for the production of special purpose software, such as visualization or signal processing software. Most of the development environments appear to be intended for Windows systems and a particular development environment will not necessarily serve all needs.

Modeling tools enable a user to construct a model using simple components capable of interaction. These tools enable the developer to coherently express his conceptual model. *Simulation development environments* automate the process of developing an simulation using similar techniques to those used in some modeling tools. Modeling tools and simulation development environments assist verification, validation, and accreditation by providing a clear and easily implemented and followed connection between the conceptual model and its electronic expression. Most tools are available as COTS.

Analysis: Surveys were received for 4 modeling tools/simulation development environments out of 10 identified. These tools appear to be useful for a broad range of applications, but a particular tool is not necessarily capable of meeting every need. As a rule, the more flexible tools will have more complex user interfaces, while the tools that are easiest to use tend to be more restrictive, although with some effort it may be possible to compensate for these restrictions. The modeling tools should be used to develop conceptual models that are easily validated. It is also important, though, that these tools be integrated in a development process that ensures the smooth transition of the conceptual model to the operational simulation and collects the necessary information for VV&A.

Federation development tools assist the developer of a distributed simulation in creating an HLA-compliant federation. These tools expedite the verification process by reducing the number of errors present in a newly developed federation. These tools have been developed with government funding.

Analysis: Surveys were not received for either of the two federation development tools identified. From the limited information provided, it is impossible to discuss these tools' performance in detail. It appears that these tools can be used to create HLA-compliant federations from legacy components.

Supporting tools include (1) visualization tools, and (2) mathematics and statistics packages. Surveys were received for 11 tools falling in the "supporting" category. An additional 15 supporting tools were identified. All of these can be considered to be primarily "supporting tools", although they may also have some other functions.

Visualization tools display data in easily understandable formats. In support of verification, visualization tools can be used to check if a system is performing to requirements, and if not, can be used to help determine the type of error. By presenting a large amount of input or output data at once, these tools make it possible to spot discrepancies. In support of validation, visualization tools help an analyst or subject matter expert determine if a system "looks right" and is representing reality correctly. Visualization tools can also be used as part of 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). In support of 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. M&S specific visualization tools differ little from general-purpose visualization tools. Most of these tools are COTS, although some that are developed for specific simulations have government sponsorship.

Analysis: Surveys were received for 7 visualization tools out of 12 identified. Visualization tools are readily available and mostly have been developed commercially, although some of the tools have had government sponsorship. The government tools tend to be somewhat more specialized. There should be a visualization tool available to meet almost any M&S need and new display techniques that enhance data presentation and clarity will continue to be developed. Some effort will need to be made to interface a model or simulation to a visualization tool, and these tools will not necessarily display data in real time.

Mathematics and statistics packages provide pre-programmed routines for the analysis of large quantities of input or output data. These tools extend the analysis performed using visualization tools and are valuable for the same purposes; many of these packages also include some visualization capability. Mathematics and statistics packages highlight the detailed discrepancies between simulation results and reality. These tools should be used in conjunction with visualization tools, since they can reveal small errors and discrepancies that visualization tools conceal or possibly even introduce. On the other hand, visualization tools occasionally reveal problems or outliers that are not discovered using the most common mathematical tests.

Analysis: Surveys were received for 4 mathematics and statistics packages out of 14 identified. All of these tools are available as COTS items. These packages provide the capability to perform virtually any mathematical analysis of simulation inputs, outputs, and intermediate data desired. This analysis cannot necessarily be performed in real time, and some effort is required to prepare data in a form suitable for these packages. Considerable effort can be required to understand and utilize the full capability of some packages.

Verification tools include (1) requirements management, specification, and tracing tools; (2) automatedtesting, measurement, and debugging tools; (3) simulation testing tools; and (4) coding standards enforcement tools.

Surveys were received for 18 of these tools out of 38 identified. All of these can be considered to be primarily "verification tools", although they may have some other functions.

Requirements management, specification, and tracing tools capture, link, trace, analyze and manage a wide range of information to ensure a project's compliance to specified requirements and standards. These tools may be used in the development of a simulation to ensure that the model or simulation performs as intended. Developing simulations using these tools should expedite verification since the possibilities of failure to meet specification are reduced and the requirements are traceable.

Analysis: Surveys were received for 6 requirements management, specification, and tracing tools out of 10 identified. These tools are primarily COTS, although some specialized tools have been developed with government support. The COTS products appear to provide most, if not all, of the capability necessary for M&S projects. Ideally, these tools should be integrated into the development environment or into the software development process.

Automated testing, measurement, and debugging tools ensure that software works as designed and is easy to maintain, understand and operate. These tools reduce the cost and increase the reliability of the verification process. Automated tools can identify and test all paths in a software system, and can perform testing more rapidly than humans. A tool to validate testing tools is included, as is an automated tool for the verification of conceptual models. All of the tools described are COTS except for two special purpose tools.

Analysis: Surveys were received for 10 automated testing, measurement, and debugging tools out of 21 identified. Many COTS products exist for testing, measurement, and debugging of software. The software metrics developed are oriented towards software engineering practice and will not satisfy all requirements for simulations. These tools should support M&S developers provided that common platforms and languages are used and the appropriate tool is selected. These tools do not address the question of validity, or the question of compliance with requirements.

Simulation testing tools collect and analyze performance data from simulations during testing. These tools support verification by providing evidence that a simulation works as intended, and may also provide information that could be used during validation to compare the simulation to reality. Some tools may be configured to produce information that would be reviewed by an accreditation agent. Some of these tools have been developed with government sponsorship, and others are COTS.

Analysis: Surveys were received for 1 simulation testing tool out of 6 identified. There is a need for more tools that can acquire simulation information that is not exchanged through the HLA RTI.

Coding standards enforcement tools reduce errors in software by checking compliance with industry-accepted coding standards. These tools assist verification by reducing the time and cost of identifying and correcting errors. These tools support accreditation by allowing the developer to state to the accreditation agent that the software has met these standards.

Analysis: A survey was received for the one COTS coding standards enforcement tool identified. These tools enforce good software engineering practice. Some of these tools provide the capability to add additional standards, which may be useful for enforcing organizational standards specific to simulation.

Configuration management tools monitor, track, and control changes to software to ensure that errors are not caused by conflicts originating in changes and that the contents and functions of software are well defined. Configuration management is useful for purposes of verification and accreditation of models and simulations because it guarantees that the desired product is the product actually being tested and disseminated.

Analysis: Surveys were received for 3 tools out of 10 identified. All of these can be considered to be primarily "configuration management tools", although they may have some other functions. The tools are all COTS. Adequate configuration management tools should be available to support any program developing M&S software provided that common platforms and languages are used.

Software costing tools estimate the development costs of software systems, including verification and validation (V&V) systems. They are useful for planning the software V&V that is part of VV&A. Testbeds for software costing tools can also be used to test models for the VV&A costs specific to modeling and simulation.

Analysis: Surveys were received for 1 tool out of 2 identified. The tools discussed are developed with government funding, although COTS software costing tools are also available. The software costing tool used in a development must be selected carefully since some of the tools make assumptions about development practices. In general, software cost modeling is an important area to which more attention should be paid.

Other tools include (1) compilation tools, (2) reliability evaluation tools, (3) database checker and design tools, (4) optimizers for simulation inputs, (5) floating point error analysis tools, (6) software analysis tools, and (7) error collection and analysis tools. Surveys were received for 3 tools out of 13 identified.

These tools do not fit readily into one of the other major categories. Most of these tools have been developed for special purposes and additional tools will need to be developed for other special purposes. The most important subcategory here may be reliability evaluation tools, which require additional effort in development and adaptation for M&S.

Reliability evaluation tools provide a structured, quantitative approach for predicting complex system performance using state of the art expert elicitation, statistical and reliability analysis, and knowledge management techniques. They support VV&A by providing information about system performance in circumstances when complete testing is impractical. This quantitative information is provided to the accreditation agent to assist with the accreditation decision.

3. Conclusions and Recommendations

3.1 Conclusions

Conclusions resulting from the detailed analysis of the VV&A automated support tools include:

- The M&S and software communities have developed many automated tools that can be used to support the verification and accreditation of models and simulations.
- The software development community leads the M&S community in this area.
- Ongoing M&S trends will increase the difficulties for VV&A and will lead to the requirements for new classes of automated support tools.
- These tools collectively satisfy many of the current functions for supporting VV&A.
- These tools need wider dissemination and they require proper use.

Desirable functions for tools supporting verification include, but are not limited to, the ability to:

- define requirements,
- trace requirements,
- document software,
- plan software tests,
- test software,
- analyze software tests,
- perform configuration management,
- create audit trails, and
- distill and present information to accreditation authorities in the appropriate formats.

Currently, no single tool satisfies all of these functions for supporting verification.

Desirable functions for tools supporting validation include, but are not limited to, the ability to compare simulation results to real world values in a meaningful manner that provides confidence in the simulation throughout its range of applicability. *Currently, the scope of automated tools that support validation is limited.* The development of validation support tools is complicated by an insufficient understanding of exactly what constitutes complete validation of a simulation. Currently, visualization tools and statistical analysis packages can be applied to validation, but purpose-built automated validation tools will not be satisfactory until such an understanding is

achieved. There are also insufficient tools available for validation of conceptual models, although some modeling tools might be useful for creating and exploring these models.

Desirable functions for tools supporting accreditation include, but are not limited to, the ability to:

- identify the information needed,
- determine if this information has been obtained, and
- acquire the information.

Currently, no single tool satisfies all of the functions for supporting accreditation.

Planning and documentation aids are applicable to all types of simulations and tend to be independent of development environment. CASE tools tend to be specialized to particular development environments. These development environment restrictions may be significant for the simulation developer who may need to select a particular tool or modify the development process, but are less important to the planner and policymaker. CASE tools, as a class, are limited in their ability to support closed-form and human/system/hardware-in-the-loop simulations relative to other types of simulations. This is not surprising since CASE tools are not typically intended for such simulations.

3.2 Recommendations

The recommendations of this paper are:

- Develop more automated support tools for VV&A.
- Adopt or adapt tools from the software industry.
- Make better use of visualization tools.
- Establish a central repository of automated support tools for VV&A.
- Develop new types of automated support tools for VV&A.

The authors hope that the Foundations '02 conference will result in a number of tools that can be added to the existing list. If a list of automated support tools is maintained at a single website and regularly updated, it could be a valuable resource for the M&S community. Such a resource would significantly reduce the time required to identify a solution to a particular problem. Obviously users would still be responsible for researching the available tools to support their problems and would need to extend that research sufficiently to feel confident that their requirements would not be better satisfied by an unlisted tool.

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Authors' Biographies

The authors of this paper were co-authors of the MSIAC VV&A SOARs. Dr. Patrick Goalwin has fifteen years of experience in DoD-related physics-based modeling and simulation, during which he has participated in four technology reviews. Dr. Jerry Feinberg has over 25 years experience in managing and conducting studies and analyses of military systems and in strategic science and technology planning. He is the Chief Scientist for the Modeling and Simulation Information Analysis Center (MSIAC).

APPENDIX A

Tool Survey Form

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?

Appendix B

Analysis Tables

This table lists tools for which a survey response was obtained.

VV&A Automated Support Tools *Surveyed*					
Tool #	**Name of Tool**	**Phase**	**Developer**	**Sponsor**	**Description**
1	Accreditation Assessment Assistant	All	Joint Accreditation Support Activity (JASA)	Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS)	Computer-based tool to guide VVA process from an accreditation standpoint
5	Analyst-Pro	Verification	Goda Software, Inc.	None/COTS	Requirements management, specification, and tracing tool
7	Artisan Real Time Studio	All	Artisan Software, Inc.	None/COTS	Modeling tool suite with UML plus real time extensions
9	Automated Requirements Measurement Tool	Verification	NASA Goddard Software Assurance Technology Center	NASA	Aid to writing requirements correctly early in life cycle
11	Axum 6.0	All	MathSoft, Inc.	None/COTS	Drawing package
15	C++test, TCA, INUSE, Jtest, insure++, WebKing	Verification	ParaSoft	None/COTS	Set of tools for memory allocation, and testing of C++ and/or/Java
16	Caliber-RBT	Verification	Technology Builders, Inc.	None/COTS	Requirements based testing design tool
17	Caliber-RM	Verification	Technology Builders, Inc.	None/COTS	Requirements management tool
18	C-Cover	Verification	Bullseye Testing Technology	None/COTS	C/C++ code testing coverage analysis tool
136	CodeWizard	Verification	ParaSoft	None/COTS	Tool for standards enforcement
19	CodeWright	Verification	Starbase Corp	None/COTS	Software development environment
22	CostModeler 1.0	All	NASA	NASA, many for COCOMO	Platform for development testing and application of software cost estimating models

23	Data Verification Interactive Editor (DAVIE)	Validation	DMSO Data Engineering	DMSO	Database or data file checker
24	Design Analysis Kit for Optimization (DAKOTA)	Verification Validation	Sandia National Laboratory (Optimization and Uncertainty Estimation Department)	Sandia National Laboratory	Toolkit to combine simulation codes with iterative methods to execute in a variety of conditions
27	Distributed Object Oriented Requirements Software (DOORS) DOORSnet	Verification	QSS Inc. (now Telelogic)	None/COTS	Requirements management and tracing tool
30	DON VVA Turbo Tool	All	IITRI ABTech Group	Navy NAVMSMO	Tool to produce standardized VVA plans and reports
34	EnSight, EnSight Gold, EnLiten, EnVideo	All	Computational Engineering, Inc.	None/COTS	Engineering and scientific visualization; is web and video enabled
36	Evaluation Environment™	All	Orca Computer, Inc.	Navy NSWCDD	Tool for conducting evaluation projects
39	Ferret	Verification	Azor, Inc.	None/COTS	Automated software testing tool
41	Genitor Object Construction Suite	Verification	Starbase Corp	None/COTS	Tools to construct, document, and reuse C++ objects
57	JASA Library of Accreditation Information (JASA)	Accreditation	Joint Accreditation Support Activity	Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS)	Descriptions of different models including problems and validation history for accreditation use; other VVA process documentation
58	JWARS V&V Database	Verification Validation	BMH Associates	JWARS Program	Database of information required by V&V agent
59	Khoros Pro 2001	Verification	Khoral, Inc.	COTS with some DARPA & AFRL	Integrated image and signal processing development environment
61	Mak Plan View Display	All	Mak Technologies, Inc.	None/COTS	2D Simulation viewer for HLA/DIS including C++ plugin
62	Mak Stealth	All	Mak Technologies, Inc.	None/COTS	3D Simulation viewer for HLA/DIS

64	MathCad	All	MathSoft, Inc.	None/COTS	General mathematics and graphics package
66	Matlab and Simulink(R)	All	The MathWorks, Inc.	None/COTS	General mathematics and display package with tools to model, simulate, and analyze dynamic systems
68	McCabe Test	Verification	McCabe & Associates	None/COTS	Automated testing tool
74	NASA/JPL WebWinds	All	NASA Jet Propulsion Laboratory (JPL)	NASA	Interactive scientific data visualization in JAVA
75	NeumaCM+	Verification Accreditation	Neuma Technology, Inc.	None/COTS	System development management tool, including configuration management, test suite management, problem tracking, and requirements tracing
77	OneSAF Testbed Baseline Plan View Display	All	US Army STRICOM	STRICOM	Simulation viewer (and GUI) for OneSAF
81	Perforce	Verification	Perforce Software, Inc.	None/COTS	Configuration management tool
85	Pro Sim 6.0	Verification	Knowledge Based Systems, Inc.	None/COTS	Process modeling, design, and knowledge capture tools
95	SAS System	All	SAS Institute, Inc.	None/COTS	Statistics, data retrieval, quality control, software performance evaluation, and data visualization package
98	Simdicator™ Toolkit	All	Litton/PRC	None/COTS	Distributed/high fidelity support, analysis, and reporting infrastructure
100	SLATE	Verification Accreditation	SDRC	None/COTS	Requirements tracing and documentation tool
102	SNIFF+	Verification	Wind River Systems, Inc	None/COTS	Software reference and analysis tool
105	SpyWright	Verification	Starbase Corp	None/COTS	Debugging tool, shows connectivity between application and source code for Windows C++ code
108	Statgraphics Plus	All	Manugistics, Inc.	None/COTS	Statistics and graphics package
109	Statistica	All	Statsoft	None/COTS	Statistics package with graphics
110	Surveyor	Verification Accreditation	Starbase Corp	None/COTS	Documentation and organization tool

113	Temporal Rover	Verification	Time Rover, Inc.	None/COTS	Specification-based verification tool for automatic verification of protocols and reactive systems
114	Temporal Verification Framework	Verification Validation	Arizona Center for Integrative M&S	Technical and Scientific Research Council of Turkey, and Arizona Center for Integrative Modeling and Simulation	Verification and validation tool for simulations and HLA federations; uses "temporal logic"
119	V&V Managers Toolkit	All	US Army Developmental Test Command and Training and Doctrine Command (TRADOC)	Army	Automated tool to guide M&S development
121	VectorCast/C VectorCast/ADA	Verification	Vector Software, Inc	None/COTS	Software testing tools for C/C++ and ADA
122	Vega	All	MultiGen-Paradigm, Inc.	None/COTS	Software development environment for simulations
124	Vermont HighTest Plus 3.2.1	Verification	Vermont Creative Software	None/COTS	Regression testing tool for Windows applications
125	Vertical Sky Solution 3.1	Verification Accreditation	Vertical Sky	None/COTS	Configuration management tools for software and web development
128	Visualization Tool Kit	All	Kitware, Inc.	None/COTS	Open source 3D visualization library
129	VVA Cost Estimating Tool (VVACET)	All	Tecmasters	Army	Parametric cost estimating tool for VVA
130	XTie-RT	Verification	Teledyne Brown Engineering	None/COTS	Requirements management and tracing tool

This table lists tools which were identified for which a survey response was not obtained.

VV&A Automated Support Tools *Identified*					
Tool #	**Name of Tool**	**Phase**	**Developer**	**Sponsor**	**Description**
2	Accreditation Support Site	Accreditation	S3I	AF Studies and Analyses Agency	Site to support accreditation of models
3	AD/Advantage	Verification	Cincom Systems, Inc.	None/COTS	Software development environment
4	Advanced Continuous Simulation Language (ACSL)	All	AEgis Technologies Group, Inc.	DMSO	Simulation development environment
8	Authoritative Data Source Library PC Version	Accreditation	DMSO	DMSO	Library of data sources including information about approved purposes
10	AVS Express	All	Advanced Visual Systems	None/COTS	General-purpose visualization package
13	BMDP	Validation	Statistical Solutions	None/COTS	Statistics package
14	BridgePoint Modeling Tools	All	Project Technology, Inc	None/COTS	Model development tools
21	COOL	Verification	Computer Associates	None/COTS	Software development environment
25	Design Point Model Compiler	All	Project Technology, Inc	None/COTS	Model compiler with development tools
26	DevPartner Studio	Verification	Compuware NuMega	None/COTS	Debugging, profiling, error checking, requirements management, and testing tool
28	Distributed Simulation Interface Framework (DSIF)	Verification	Georgia Tech Research Institute (GTRI)	DMSO	Software development tool for distributed simulations
29	Doc Express	Accreditation	ATA, Inc.	None/COTS	Automated documentation generation tool suite
31	EDGE Viewer	All	Autometric, Inc.	COTS product may have some Government involvement	Visualization tool

32	EFFTool	Verification	National Institute of Standards and Technology (NIST)	NIST	Error collection and analysis software
33	Endevor Workstation and other Endevor products	Verification Accreditation	Computer Associates	None/COTS	Configuration management tools
35	ERwin	Verification	Computer Associates	None/COTS	Database design tool
134	eValid	Verification	eValid, Inc.	None/COTS	Test enabled browser technology
37	Fault Determination Measurement System	Verification	Cylant Technology, Inc.	None/COTS	Software metrics package
38	Federation Verification Tool (FVT)	Verification	Georgia Tech Research Institute (GTRI)	DMSO	Works through HLA to monitor behavior of federation
40	Forte' Products	Verification	Sun Microsystems	None/COTS	Software development environment
42	Genstat	Validation	NAG, Inc.	None/COTS	Statistics and data visualization package
43	GLIM	Validation	NAG, Inc.	None/COTS	Statistics package
44	Hindsight	Verification Accreditation	IntegriSoft, Inc.	None/COTS	Testing, documentation, metrics, and code analyzer
133	HLA Control	Verification Accreditation	Virtual Technology Corporation	None/COTS	Federation planning, execution, and performance analysis tool
45	HLA Lab Works Suite of Tools	Verification Accreditation	AEgis Technologies Group, Inc.	DMSO	Federation development tool to create HLA compliant federations.
132	HLA Results	Verification Accreditation	Virtual Technology Corporation	None/COTS	Federation data collection, playback, and analysis system
48	IBM Open Visualization Data Explorer	All	IBM	None/COTS	General-purpose data visualization package
49	IDEF	Verification	Knowledge Based Systems, Inc.	Government Standard Page maintained commercially	Requirements development, process, information and data modeling language
50	Imagix 4D	Accreditation	Imagix Corporation	None/COTS	Software documentation tool
52	Interval Arithmetic	Validation	Sun	COTS	Useful for treating roundoff error and observational uncertainty

53	IRIS Explorer	All	NAG, Inc.	None/COTS	Visualization system and application builder
54	ISE Eiffel	Verification	Integrated Software Engineering	None/COTS	Software development environment
55	ITrace SE	Verification	ITrace LLC	None/COTS	Requirements traceability and management and testing tool
56	IV&V Effort Estimator	Verification Validation	AverStar formerly Intermetrics	NASA	Planning/costing tool
63	Maple	All	Waterloo Maple, Inc.	None/COTS	General computational and plotting software
65	Mathematica	All	Wolfram Research, Inc.	None/COTS	Mathematical toolkit with graphics; as much a programming language as a toolkit
69	Metamata Development Environment	Verification	Metamata, Inc.	None/COTS	Development environment for Java including metrics
135	Microsoft Access 2000	All	Microsoft	None/COTS	Database development tool
70	Minitab	All	Minitab, Inc.	None/COTS	Statistical and graphical analysis
71	ModelMart	All	Computer Associates	None/COTS	Model management tool and collaborative development environment
72	ModIOS 3D Stealth Viewer	All	Motorola Corp.	None/COTS	Simulation viewer for HLA/DIS
73	Monte Carlo Arithmetic	Validation	UCLA	Not Known	Error analysis for floating point arithmetic
78	Openmake	Verification	Catalyst Systems Corporation	None/COTS	Tool for standardizing software builds
79	Panorama 2	Verification	International Software Automation, Inc.	None/COTS	Software testing and defect tracing tool
80	PerfMETRICS	Verification	BMH Associates	Multiple programs	Runtime performance data collector for distributed simulations
82	PEST	Verification	National Institute of Standards and Technology	NIST	Program with known bugs to test automated testing tools
83	Platinum CCC/Harvest	Verification Accreditation	Computer Associates International	None/COTS	Configuration management tool
84	PREDICT	All	Los Alamos National Laboratory	Department of Energy	Reliability evaluation tool

86	PVCS	Verification Accreditation	Merant	None/COTS	Configuration management tool
87	PV-WAVE	All	Visual Numerics, Inc.	None/COTS	General mathematics and display package
88	QACenter	Verification	Compuware, Inc.	None/COTS	Software requirements tracing and testing toolset
89	Rational Suite	Verification	Rational Software, Inc.	None/COTS	Software development environment with design, development, test, and analysis features
90	Razor	Verification Accreditation	Visible Systems Corporation	None/COTS	Configuration management tool
91	RDD-100	Verification	Ascent Logic	None/COTS	Requirements tracing tool
92	Reactor	Verification	Critical Mass, Inc.	None/COTS	Software development environment
93	RTM	Verification	Integrated Chipware,Inc.	None/COTS	Requirements traceability and management
94	Sablime	Verification Accreditation	Lucent Technologies	None/COTS	Configuration management tool
96	SENSE8	All	Engineering Animation, Inc.	None/COTS	3D visual simulation development environment
97	Silk Product Family	Verification	Segue, Inc.	None/COTS	Testing, usage monitoring, modeling, and defect tracking tools
101	SLIM	Verification	Quantitative Software Management, Inc.	None/COTS	Software lifecycle management tool for estimating, tracking, and benchmarking
103	Software through Pictures	Verification	Aonix, Inc.	None/COTS	Software development environment
104	S-Plus	All	MathSoft, Inc.	None/COTS	Statistics and data visualization package
106	StarTeam	Verification Accreditation	Starbase Corp	None/COTS	Configuration management tool
107	STATA	All	Stata Corporation	None/COTS	Statistics and data visualization package
137	Symbolic Model Verifier	Verification Validation	Software Engineering Institute	Joint SEI Program Office	Finite state system model checking tool
111	Systat 10	All	SPSS Science	None/COTS	Statistics package with graphics
112	TARZAN	Validation	NASA	NASA	Monte Carlo technique with pruning for simulation testing over a parameter space
115	Test Center	Verification	Centerline Development Systems	None/COTS	C/C++ testing tool

116	TestWorks	Verification	Software Research, Inc.	None/COTS	Testing tool including metrics and coverage checking and debugging assistance
117	Understand Family, Source Publisher, QualGen, DocGen	Verification Accreditation	Scientific Toolworks, Inc.	None/COTS	Documentation and metrics tools
118	Unravel	Verification	National Institute of Standards and Technology (NIST)	NIST	Program to extract all statements relevant to a variable in source code
120	Validator/Req	Verification	Aonix, Inc.	None/COTS	Requirements development tool
126	Visible Advantage	Verification	Visible Systems Corporation	None/COTS	Software engineering and data warehouse development tools
131	VisualAge Smalltalk UML Designer	Validation	IBM	None/COTS	Modeling and requirements capture
127	Visual Source Safe 6.0	Verification Accreditation	Microsoft	None/COTS	Configuration management tool

This table cross-references tool use by sponsor.

Sponsor Versus Tool Use: Cross Reference Table							
	Sponsor						
Use of Tool	**Army**	**Navy / Marines**	**Air Force**	**Other DoD**	**Other Govern-ment**	**Commercial**	**Mixed***
Direct Support of Verification	119	30, 36		38, 58, 80, 137	24, 32, 84, 114, 118	5, 15, 16, 17, 18, 27, 37, 39, 44, 55, 68, 79, 88, 91, 93, 95, 97, 100, 101, 105, 113, 115, 116, 121, 124, 130, 132, 133, 134	
Indirect Support of Verification	77, 129			1, 4, 28, 45	9, 22, 74, 82, 56	3, 7, 10, 11, 14, 19, 21, 25, 26, 33, 34, 35, 40, 41, 42, 48, 53, 54, 61, 62, 64, 65, 66, 70, 69, 71, 72, 75, 78, 81, 83, 85, 86, 87, 89, 90, 92, 94, 96, 98, 102, 103, 104, 106, 107, 108, 109, 110, 111, 117, 120, 122, 125, 126, 127, 128, 135, 136	31, 49, 59
Direct Support of Validation	119	30, 36		58	112, 114		
Indirect Support of Validation	77, 129			1, 4, 137	22, 23, 24, 56, 73, 74, 84	7, 10, 11, 13, 14, 25, 34, 42, 43, 48, 52, 53, 61, 62, 63, 64, 65, 66, 70, 71, 72, 87, 95, 96, 98, 104, 107, 108, 109, 111, 122, 128, 131, 135	31
Direct Support of Accreditation	119	30, 36	2	1, 57			
Indirect Support of Accreditation	77, 129			4, 8, 45	22, 74, 84	7, 10, 11, 14, 25, 29, 33, 34, 41, 42, 44, 48, 50, 53, 61, 62, 64, 65, 66, 70, 71, 72, 75, 81, 83, 86, 87, 90, 94, 95, 96, 98, 100, 104, 106, 107, 108, 109, 110, 111, 117, 122, 125, 127, 128, 132, 133, 135, 136	31

This table cross-references tool type by sponsor.

Sponsor Versus Tool Type: Cross Reference Table							
	Sponsorship of Different Types of Tools						
Type of Tool	**Army**	**Navy / Marines**	**Air Force**	**Other DoD**	**Other Govern-ment**	**Commercial**	**Mixed***
RESOURCES							
Resources			2	8, 57, 58			
DOCUMENTATION TOOLS							
Planning / Documentation Aids	119, 129	30, 36		1			
Software Documentation Tools						29, 50, 110, 117	
DEVELOPMENT ENVIRONMENTS							
Software Development Environments						3, 19, 21, 26, 40, 41, 54, 69, 89, 92, 103	59
Modeling Tools / Simulation Development Environments				4		7, 14, 71, 85, 96, 98, 122, 131	49
Federation Development Tools				28, 45			
SUPPORTING TOOLS							
Visualization Tools	77				74	10, 11, 34, 48, 61, 62, 72, 128, 53	31
Math and Statistics Packages						13, 42, 43, 63, 64, 65, 66, 70, 87, 104, 107, 108, 109, 111	
VERIFICATION TOOLS							
Requirements Management, Specification, and Tracing Tools					9	5, 17, 27, 55, 91, 93, 100, 120, 130	
Automated Testing / Measurement / Debugging Tools				137	82	15, 16, 18, 37, 39, 44, 68, 79, 88, 95, 97, 101, 105, 113, 115, 116, 121, 124, 134	
Simulation Testing Tools				38, 80	112, 114	132, 133	
Coding Standards Enforcement Tools						136	
CONFIGURATION MANAGEMENT TOOLS							
Configuration Management Tools						33, 75, 81, 83, 86, 90, 94, 106, 125, 127	
SOFTWARE COSTING TOOLS							

Software Costing Tools					22, 56		
OTHERS							
Compilation Tools						25, 78	
Reliability Evaluation Tools					84		
Database Checkers / Design Tools				23		35, 126, 135	
Optimizers for Simulation Inputs					24		
Floating Point Error Analysis Tools					73	52	
Software Analysis Tools					118	102	
Error Collection and Analysis Tools					32		

This table cross-references tool use by tool type.

Tool Use Versus Tool Type: Cross Reference Table						
	Use of Different Types of Tools					
Type of Tool	**Direct Support of Verification**	**Indirect Support of Verification**	**Direct Support of Validation**	**Indirect Support of Validation**	**Direct Support of Accreditation**	**Indirect Support of Accreditation**
RESOURCES						
Resources	58		58		2, 57	8
DOCUMENTATION TOOLS						
Planning / Documentation Aids	30, 36, 119	1, 129	30, 36, 119	1, 129	1, 30, 36, 119	129
Software Documentation Tools		110, 117				29, 50, 110, 117
DEVELOPMENT ENVIRONMENTS						
Software Development Environments		3, 19, 21, 26, 40, 41, 54, 59, 69, 89, 92, 103				41
Modeling Tools / Simulation Development Environments		4, 7, 14, 49, 71, 85, 96, 98, 122		4, 7, 14, 71, 96, 98, 122, 131		4, 7, 14, 71, 96, 98, 122
Federation Development Tools		28, 45				45
SUPPORTING TOOLS						
Visualization Tools		10, 11, 31, 34, 48, 53, 61, 62, 72, 74, 77, 128		10, 11, 31, 34, 48, 53, 61, 62, 72, 74, 77, 104, 128		10, 11, 31, 34, 48, 53, 61, 62, 72, 74, 77, 104, 128
Math and Statistics Packages		42, 64, 65, 66, 70, 87, 104, 107, 108, 109, 111		13, 42, 43, 63, 64, 65, 66, 70, 87, 107, 108, 109, 111		65, 66, 64, 42, 70, 87, 107, 108, 109, 111
VERIFICATION TOOLS						
Requirements Management, Specification, and Tracing Tools	5, 17, 27, 55, 91, 93, 100, 130	9, 120				100

Automated Testing / Measurement / Debugging Tools	15, 16, 18, 37, 39, 44, 68, 79, 88, 95, 97, 101, 105, 113, 115, 116, 121, 124, 134, 137	82		95, 137		44, 95
Simulation Testing Tools	38, 80, 114, 133, 132		112, 114			132, 133
Coding Standards Enforcement Tools		136				136
CONFIGURATION MANAGEMENT TOOLS						
Configuration Management Tools		33, 75, 81, 83, 86, 90, 94, 106, 125, 127				33, 75, 81, 83, 86, 90, 94, 106, 125, 127
SOFTWARE COSTING TOOLS						
Software Costing Tools		22, 56		22, 56		22
OTHERS						
Compilation Tools		25, 78		25		25
Reliability Evaluation Tools	84			84		84
Database Checkers / Design Tools		35, 135, 126		23, 135		135
Optimizers for Simulation Inputs	24			24		
Floating Point Error Analysis Tools				52, 73		
Software Analysis Tools	118	102				
Error Collection and Analysis Tools	32					