Simulation Verification, Validation, and Accreditation

Simone M. Youngblood, Dale K. Pace, Peter L. Eirich, Donna M. Gregg, and James E. Coolahan

Amazing advances in software, computer, and network technology occurred during the 1990s. These advances contributed significantly to the increasing impact of models and simulations on numerous scientific and defense-related domains including medical diagnosis, system acquisition and development, planning and analysis, and training. A growing emphasis on processes that ensure that computer models and simulations perform correctly and that appropriate confidence is placed in their results has accompanied this increased use of models and simulations. Verification, validation, and accreditation (VV&A) serve as the cornerstones of simulation correctness and credibility. This article discusses APL's leading role in DoD's VV&A activities and describes the Laboratory's contribution to advances in VV&A methodology. (Keywords: Credibility, Model, Simulation.)

INTRODUCTION

DoD uses simulation in many ways: pilots train in full range-of-motion simulators with simulated views of the real world appearing outside the canopy; parachutists are strapped into a test harness and "fall" through the simulated sky that they view through high-technology goggles; a proposed weapon system is designed and prototyped using simulation-based concepts; a virtual battle is conducted at geographically dispersed sites. Although the potential for the application of simulations within DoD appears limitless, the level of confidence that can be placed in simulations and their credibility have been uncertain.

Verification, validation, and accreditation (VV&A) seeks to address simulation credibility and acceptance. Focused on simulation structural integrity, verification evaluates whether simulation specifications have been met. Validation focuses on simulation representations. Accreditation is a management judgment that simulation credibility (its perceived correctness) is appropriate for use in the application under consideration. In other words, verification determines if the simulation was built right, validation determines if the right thing was built, and accreditation determines if it is appropriate for a particular use.

The concept of verification and validation (V&V) is not unique to DoD modeling and simulation (M&S). Historically, V&V has been pivotal in the development of space shuttle software, medical software, and software and simulations that support nuclear reactors. However, in the early to mid-1990s, V&V became

more prominent in the defense community. Additionally, the emphasis on a formal "sign off" was increased through accreditation.

As more attention was given to VV&A, DoD developed standards, policy, and guidelines that would support the implementation of VV&A concepts. APL's Joint Warfare Analysis Department (JWAD) has been at the forefront of DoD VV&A for many years, contributing to the definition of key concepts and supporting the evolution of policy and process. The Laboratory has also been actively involved in VV&A activities supporting a variety of defense programs. The following sections provide an overview of DoD VV&A policy development, a glimpse of VV&A accomplishments and contributions made by Laboratory personnel, and the far-reaching impact that APL has had on defense VV&A.

THE EVOLUTION OF DOD VV&A POLICY

DoD's emphasis on M&S management resulted in the publication of DoD Directive 5000.59 in 1994, which mandated that the military services and defense agencies address the issue of simulation credibility. They were to accomplish this by establishing

> . . . VV&A policies and procedures for modeling and simulation applications managed by that DoD Service/Component [and by serving as] . . . final authority for validating and accrediting representations of its own forces and capabilities in joint and common use M&S.

The directive also required accreditation for M&S used to support major DoD decision-making organizations (e.g., Defense Acquisition Board) and M&S used for Joint training.

DoD then produced an umbrella VV&A instruction in 1996, DoD Instruction 5000.61, to implement policy, assign responsibilities, and prescribe procedures for VV&A of DoD M&S. They later published the DoD *VV&A Recommended Practices Guide* (RPG) that defines principles, processes, and techniques recommended for use in DoD VV&A efforts. The November 1996 version of the RPG provided M&S users, managers, developers, and VV&A agents and personnel with a basic understanding of VV&A terminology, techniques, and processes. (These documents can be accessed through the Defense Modeling and Simulation Office [DMSO] Web site, http://www.dmso.mil.)

In response to DoD Directive 5000.59, the Army, Air Force, and Department of the Navy (including the Marine Corps) issued instructions that established VV&A policies and procedures (accessible via http://rac.iitri.org/SIDAC/PRODUCTS/models/modlinks/policy.html). Likewise, VV&A instructions have been developed for other DoD components: the Joint Staff, the Ballistic Missile Defense Organization (BMDO), and the National Security Agency (NSA).

PAST VV&A ACCOMPLISHMENTS AT APL

Leadership Roles

The Laboratory has been involved in computer simulation since the early 1950s. During that time, Robert Rich,[1] as an APL staff member, invented the important and widely used event-store method of simulation time management. APL's VV&A competence arose from grappling with the correctness of its simulations and their associated software. As a result of the recognition of its capabilities in this arena, the Laboratory was given leadership roles in reviews of the correctness and credibility of simulations developed or used by both the Laboratory and others. The breadth and depth of VV&A activities in which the Laboratory has been involved are indicative of APL's influence in the larger defense community.

APL's current VV&A leadership roles include co-chairing the Tomahawk Simulation Management Board, which oversees certification of simulations used in the Tomahawk programs. APL has had similar responsibilities in simulation activities for the HARM and Standard Missile communities. In the mid-1980s, APL led a multiorganization DoD/Department of Energy team that reviewed a simulation developed by Sandia National Laboratories concerning a possible nuclear-armed version of Standard Missile.[2] In the early 1990s, APL led a team that reviewed more than a dozen simulations at Navy R&D centers for the Space and Naval Warfare Systems Command (SPAWAR).

The Laboratory was also called upon to draft initial VV&A plans for the Naval Simulation System (NSS) and helped the Navy articulate its requirements for the NSS and for Joint warfare simulations. Currently the Laboratory serves as the validation lead for the independent V&V (IV&V) team reviewing the National Missile Defense Human-in-Control simulation, Wargame 2000 (discussed further in a later section). APL is also helping the Navy develop standardized approaches (templates) for VV&A information used in OPNAV analyses.

Standards Development

APL's role in simulation VV&A has gone far beyond its involvement in reviews of specific simulations. The basic VV&A bibliography made available to the defense community at large via the DMSO Web site noted earlier was developed by APL. The Laboratory served as the technical lead for development of the Navy's 1993 *Interim Policy Guidance (IPG) on Verification, Validation, and Accreditation (VV&A) Policies, Procedures, and Guidelines for Navy Model and Simulation (M&S) Applications* and participated in the development and updating of the RPG. APL personnel have

chaired or co-chaired the VV&A forums for distributed simulation standards since they began in 1993. The first forums were conducted for the Distributed Interoperability Simulation (DIS) community, which led to IEEE Std 1278.4 on VV&A for DIS exercises with its famous "9-step" process. APL now chairs the Simulation Interoperability Standards Organizations workshops, which are oriented toward high-level architecture (HLA).

APL is also helping NSA develop its simulation VV&A policy and processes. Since 1997, an APL staff member on an interagency assignment has served as the VV&A Technical Director for DMSO/DoD's focal point for VV&A. As well as providing general guidance about VV&A in openly available publications,[3,4] APL personnel developed and taught VV&A short courses for government, industry, and professional societies. They have provided VV&A leadership for professional societies such as the Military Operations Research Society (MORS), serving on the MORS Simulation Validation (SIMVAL) Senior Advisory Group and co-chairing the 1999 SIMVAL workshop. APL staff members have also led VV&A tracks at the Society for Computer Simulation International conferences and serves as the associate editor for validations for its journal, *Simulation*.

VV&A AT DMSO

APL's extensive impact on DoD VV&A policy development is evident in the assignment of an APL staff member as the technical lead for the DMSO VV&A Program. DMSO was established on 21 June 1991 to provide a full-time focal point for information concerning DoD M&S activities. DMSO promulgates M&S policy, initiatives, and guidance to promote cooperation among DoD components. As identified in its mission statement, DMSO functions include

> . . . distributing USD(A&T) approved guidelines . . . in the areas of . . . verification, validation, accreditation [and] developing USD(A&T) approved liaison processes to coordinate and assist in the development, acquisition, and sharing of . . . verification, validation, and accreditation processes.

The DMSO VV&A Program focuses on two primary concepts: quality assurance and risk management. Quality assurance addresses M&S credibility and formalism in development and application by incorporating authoritative representations and behaviors. Risk management highlights methodologies for identifying errors early in the M&S development life cycle and suggesting mitigation strategies. Key objectives of the current program include enhancement of DoD VV&A policy and guidance, development of specifications for reuse, and development of methodologies that support VV&A of HLA federations.

VV&A Policy and Guidance

In 1998, DMSO identified a need to update existing VV&A policy and evolve recommended practices to reflect changing concepts and emerging technologies. In response, two teams were formed: a government team serving under the auspices of the DoD VV&A Technical Working Group and a technical support team serving under the DMSO VV&A Technical Director. The government team, which was co-chaired by the DMSO VV&A Technical Director, undertook the revision to DoD Instruction 5000.61. The revision, which was completed in July 1999 and is currently being staffed through DoD, clarifies roles and responsibilities, clarifies the relationship of data and simulation V&V, and ensures terminology consistency with DoD VV&A guidance.

Whereas the government team membership was drawn from the Service and DoD component VV&A points of contact (e.g., Defense Intelligence Agency, NSA, etc.), the technical support team drew experts from government, industry, and academia. The resulting team contained an impressive array of experts that included several of the most prominent VV&A authors in the nation.[5–9] This group was charged with evolving the 1996 RPG by taking the generic theoretical framework and creating an applications-based guidance document that emphasizes the different roles or players who impact or are impacted by V&V. The revised Web-based RPG provides potential users information on VV&A from different perspectives as well as at different levels of detail. It serves as an important resource to the DoD community. Besides the development of policy and guidance, the DoD VV&A Program actively supports ongoing DoD programs such as the Joint Simulation System.

Specifications for Reuse

In addition to producing guidance, the DMSO VV&A Program is focused on addressing several key issues that are critical elements of VV&A. One such issue that has a direct bearing on the DoD guiding principles of reuse and interoperability is specifications for reuse, i.e., the development of standard methods for describing simulations. These specifications would include standard methods for describing a simulation's conceptual model, its underlying assumptions and limitations, critical algorithms, and VV&A histories (for models, simulations, and associated data). APL staff are actively involved in drafting proposed reporting and descriptive standards, particularly in the development of conceptual model descriptions.

VV&A of HLA Federations

The HLA Federation Development and Execution Process (FEDEP; see http://hla.dmso.mil/federation/fedep)

is a 6-phase process model designed to guide federation managers, developers, and integrators through the process of constructing a federation, defining the activities, roles, and expected products at each phase. A VV&A process overlay of the FEDEP was developed to be used in parallel with the FEDEP. This process, which defines the core VV&A objectives, activities, and products within each phase of the FEDEP, is based on VV&A lessons learned and experiences. The completed VV&A overlay has been incorporated into the revised VV&A RPG.

VV&A IN SUPPORT OF NSA

M&S is used by NSA to support signals intelligence (SIGINT) and information security (INFOSEC) programs. Because of the increasing reliance on M&S, NSA developed a regulation on VV&A to address M&S credibility issues. This regulation provides policy for NSA VV&A activities and establishes criteria for their applicability to agency programs and roles and responsibilities. It enhances the correctness and credibility of SIGINT and INFOSEC models and simulations and their results. The policy identifies NSA as the validating agent for those portions of internal or external M&S with SIGINT or INFOSEC components.

NSA has also prepared a validation practices and procedures guide to further support internal and external validation efforts. The guide defines a 6-step validation process that begins with an initial review conducted by NSA. During the review, a model or simulation will be accepted for validation, granted a waiver, or possibly refused because of NSA knowledge of existing agency models that provide the needed SIGINT or INFOSEC functionality. Early NSA involvement with M&S developers and users allows V&V costs and activities to be planned from the beginning. APL played a key role in helping NSA develop both its VV&A regulations and its validation practices and procedures guide.

The 6-step validation process includes defining acceptability criteria as well as validation planning and execution. It culminates in an NSA-approved validation report and accommodates a mix of roles and responsibilities, depending on the customer's needs and budget. NSA normally performs all validation activities either directly or through a validation agent. However, when the budget or project size requires the model or simulation developer to perform validation activities, NSA maintains final approval authority on all these activities and the validation report.

NSA built flexibility into its validation process to reflect different kinds of M&S applications. The agency recognizes that the confidence in correctness needed or achievable will vary depending on the application type. For example, a simulation involving safety of life or the safety of critical systems must produce accurate results *all* the time. However, the acceptable confidence in correctness of other applications may be lower because of the nature of the application and, in some cases, may be limited by available validation resources. The NSA regulation provides three levels of validation, depending on the desired confidence in the model or simulation. NSA validation activities then scale to that level.

The VV&A regulation and the validation practices and procedures guide represent an important step by the agency. NSA recognizes its role in assuring the credibility and validity of all SIGINT and INFOSEC models and simulations. In light of decisions made using these models, NSA realizes that having appropriate confidence in their correctness is critical. The agency's commitment to the validation of SIGINT and INFOSEC representations benefits the entire M&S community.

VV&A IN SUPPORT OF WARGAME 2000

BMDO is developing Wargame 2000 at the Joint National Test Facility to address missile defense concepts of operation and related topics. Wargame 2000 development, started in 1997, initially focused on national missile defense (NMD) issues. Reaching its initial operating capability in January 1999, Wargame 2000 replaced the Argus wargaming system previously used as a NMD command and control simulation. When fully developed, Wargame 2000 is expected to be capable of addressing both NMD and theater air and missile defense issues.

The IV&V Team

In support of Wargame 2000 development, BMDO established a multipart IV&V team to supplement V&V activities performed by the Wargame 2000 developer. The IV&V team is tasked through the BMDO Phase One Engineering Team, an analytical support element of BMDO whose participants include the Department of Energy, national weapon laboratories, federally funded R&D centers, and APL. The Laboratory is the IV&V team validation lead.

The IV&V team created a context for Wargame 2000 VV&A by identifying all defense community VV&A policies that might pertain to the wargame, reviewing the scope of user or sponsor input to its requirements, and defining processes for describing conceptual models[10,11] for items represented in it. The team also defined anticipated content and format for conceptual validation reviews and developed processes for the management of subject-matter experts

(SMEs) involved in the wargame reviews.[12] Finally, the IV&V team drafted acceptability criteria for Wargame 2000 accreditation authorities, oversaw and participated in SME validation reviews of the wargame, and contributed to the VV&A strategy for NMD simulations.

Conceptual Models

Initially, descriptive formats for conceptual models of systems such as the ground-based radar and the ground-based interceptor represented in Wargame 2000 were a problem. The defense simulation community has not yet established standard approaches for describing simulation conceptual models, and separate documentation of them for Wargame 2000 systems was not required by the work orders for the first version (Block 10). The Wargame 2000 developer tried to use existing documentation, such as software design descriptions or detailed software requirements for conceptual validation reviews. As might be expected from this approach,[13] misinterpretations made by SMEs during conceptual model validation resulted in conceptual models that were not as complete nor as robust as desired.

Descriptive formats for conceptual models for the next version of Wargame 2000 (Block 20) moved toward an approach that has been suggested for the defense community as a whole.[10] This approach uses the scientific paper format to describe simulation conceptual models so that the description is generally understandable to technically competent people, more likely to be logically complete (especially in terms of explicitly identifying assumptions and limitations), and should contain more robust data and algorithms.

Acceptability Criteria

Acceptability criteria are a subset of simulation requirements that have special importance for a particular application. They identify specific test conditions that must be demonstrated for accreditation. Accreditation authorities, typically the users of a simulation in a particular application, usually do not articulate acceptability criteria as early as needed or in the detail needed to ensure that both the simulation developer and the V&V team have adequate guidance to perform their responsibilities efficiently and effectively. The APL-led validation portion of the Wargame 2000 IV&V team helped BMDO develop a process for the early articulation of acceptability criteria. In this process, user objectives for a specific application of the wargame are expanded into a set of specific and testable criteria by the IV&V validation team. These criteria are then reviewed by the wargame developer to identify potential impact on the development schedule and cost. The accreditation authorities then publish the formal acceptability criteria, which help focus conceptual validation and results validation reviews.

SOME RECENT APL VV&A PROJECTS FOR THE NAVY

The SECNAV instruction on VV&A, SECNAVINST 5200.40,[14] provides the rationale and a framework for tailoring key VV&A processes to any Navy M&S effort such as a new development, a legacy modification, or a simulation federation development. It also specifies criteria to determine the applicability of the instruction to any Navy M&S project. The Navy Modeling and Simulation Management Office (NAVMSMO) provides additional support for Navy VV&A efforts with a program that emphasizes acceptability criteria, risk assessment, planning and budgeting for V&V activities, cost estimation, validation techniques, skill requirements, and guidance regarding the key roles in VV&A.

Within this context of Navy VV&A initiatives, personnel from JWAD are engaged in two innovative VV&A applications. The first is the development of templates for online entry of VV&A information during the conduct of Navy studies and analyses. These have been developed for use by the Chief of Naval Operations Assessment Division (N81). The second is development of part of the VV&A process for the 21st Century Surface Combatant (SC 21) for the program office (NAVSEA PMS-500). Both are discussed below.

VV&A Work for N81

Data Templates and RMS

In 1999, a series of data templates to facilitate and simplify capture of VV&A information during studies and analyses were developed for N81 under the guidance of the Strategic Planning Branch. The objective was to implement Navy VV&A policy (SECNAVINST 5200.40)[14] with a process that would satisfy its goals but not add an undue burden to N81 workload. The solution, which was tested at N81 in 1999, involved incorporating the collection of V&V information as seamlessly as possible into existing procedures for N81 studies and analyses. For this application, N81 had the benefit of a Resource Management System (RMS)—a network application for supporting technical work that was already being used to manage the documents and data sources for a study. A networked application such as the RMS has the added advantage that analysts at multiple locations can coordinate their entries to create a cohesive picture for V&V. Accordingly, the approach for collecting the necessary V&V

information was designed to take full advantage of the RMS.

The N81 V&V concept allows an analyst to enter V&V-related information, as it is developed during a study effort, directly into the RMS. Implementing this concept necessitated designing a series of entry screens compatible with the RMS architecture in order to capture V&V results and to enable them to be hyperlinked to other related data files in the study. For example, if a series of tests were conducted as part of the verification process for a particular model, the test results would be documented using the appropriate V&V template, which would provide direct links to descriptions of both the model and its use in support of the study. Similarly, the completed V&V templates would also be hyperlinked, permitting all the relevant V&V information to be readily gathered into comprehensive V&V reports for model accreditation and data source certification.

Two templates developed in this endeavor that respond directly to the SECNAVINST 5200.40 process are the N81 template for data source V&V and the N81 template for model V&V. The data source template records the information concerning a data source that can verify that the data are generally suitable for use within N81 studies. The model template is designed to record the relevant V&V information concerning a model or a simulation that is generated at each step of the process defined by SECNAVINST 5200.40, and also to document the organizational and individual responsibility for providing this V&V information. However, since accreditation of a model signifies its acceptability for a specific application, accreditation conclusions are *not* recorded in the model template. Within N81, a specific application is established by the way a model is used to support a particular study or analysis effort. For this reason, official N81 decisions on model accreditation and data source certification (the data counterpart to model accreditation) are recorded within a third template for campaign study or wargame V&V.

The N81 template for campaign study or wargame V&V recognizes that otherwise acceptable stand-alone models might not work well together in certain combinations and provides an area to indicate the acceptability of model-to-model interactions. N81 wanted to extend the template approach to the entire study or analysis efforts. For this reason, this template serves an additional purpose: it provides a means to record information about the overall study approach used, the study results, and their areas of applicability. The V&V information to be included for a study was based on a generalization of the SECNAVINST 5200.40 principles for model V&V. The official N81 decision that the results of a study may be considered as being accredited by N81 is also recorded in this template.

Efficiency Issues

The objective of ensuring that the implementation of a formal V&V process did not place an unworkable burden on N81 studies required that three different aspects of efficiency be incorporated into the template designs. First, the templates are designed to facilitate electronic data entry. The prototype usage of the templates, initially employed in the form of word processing documents, was initiated only *after* the RMS developers had determined that the RMS architecture could generally support the requirements of the templates and that implementation of all necessary modifications to the architecture would be feasible. Second, by providing a series of specific V&V entries in a logical sequence, the templates provide a straightforward and efficient work flow. Finally, by closely tailoring the content of the V&V entries to the specific nature of the work performed by N81 and to the typical sequence of the study tasks, the templates do not collect information that is not needed by N81 for accreditation purposes.

The most significant "lesson learned" from this project is the importance of carefully tailoring an overall V&V approach to the specific situation of the organization that will be applying it. If these N81 templates were to be applied within another organization, there would be substantial changes both in the nature of the V&V questions included and in the overall V&V work flow implied, even while still remaining consistent with the overall VV&A process as presented in SECNAVINST 5200.40.

VV&A Work for the SC 21 Program Office

The SC 21 Program Office is concerned with acquisition of the DD 21 littoral warfare ship, the first in a series of classes of SC 21s. The DD 21 Program is pursuing an innovative procurement approach wherein there is a much closer cooperative working relationship between government and industry, particularly in the early stages, than has been typical in the past. For example, government representatives are included in integrated product team meetings held by each of the competing teams. Consequently, it would be reasonable to anticipate that VV&A processes adopted by the SC 21 Program would have unique aspects, i.e., features designed to take full advantage of the potential benefits from the cooperative DD 21 procurement approach. In support of this effort, JWAD is participating on the DD 21 M&S core team, which is responsible for preparing a proposed VV&A process for consideration by the SC 21 Program Office. Within the core team, JWAD is also participating on the VV&A subteam that is drafting the VV&A process document for DD 21 use.

FUTURE VV&A CHALLENGES

Increased Use

Advances in computational hardware and software are allowing (and causing) simulation results to be relied on as the basis for planning, development, and operation decisions. Planning can encompass all aspects of a problem before initiation of design. For example, in the defense community, a simulation could be used to analyze required force levels and their capabilities. Development addresses R&D, design, and engineering applications, including test and evaluation activities. In some cases, simulation results are used as a surrogate for or a supplement to testing. This can be due to economics or because environmental or safety considerations preclude testing under desired conditions. Operation is concerned with system use and can include a variety of activities from analysis of concepts of operation to simulation-based decision aids that support real-time activities such as flying a plane, driving a tank, or managing a manufacturing plant.

These evolving simulation capabilities pose many VV&A challenges. The increased use of simulations for decision making stresses the importance of appropriate administrative processes to authorize the use of simulation results in this way (the accreditation issue). The increased use of simulations also magnifies the importance of adequate technical processes (V&V) to ensure that a simulation can support its intended application.

Affordability and Complexity

There is also the pragmatic issue of affordable and effective V&V. Computational advances mean that simulations are likely to be larger since faster computers are available to run larger programs and software development environments allow more reuse of code. They are also likely to be more complex. For example, Buchanan[15] describes a simulation of the human heart that has 30 million equations. Some simulations will employ complex adaptive processes, such as rule-driven, knowledge-based systems, which are amenable to logical assessment using formal methods. Other complex adaptive processes, such as those involved in neural networks and genetic algorithms, are not amenable to logical assessment; only their performance in particular applications can be assessed. This can make it difficult to predict the likelihood that simulation performance will be acceptable in untested situations. Sometimes simulation complexity will arise because the simulation includes hardware, software, people, or systems in the loop.

Larger simulation size and increased complexity combine to make V&V more difficult and potentially more costly. Advances in V&V technology to increase V&V automation[16] in ways comparable to how computer-aided software engineering tools have automated software documentation, configuration management, etc., may be an important part of addressing this challenge.

Verification, validation, and accreditation (VV&A) serve as the cornerstones of simulation correctness and credibility.

Distributed Interactive Simulation

Another VV&A challenge area is the growing use of distributed simulation. During the past decade, the capability to link simulations has increased significantly within the defense communities of America and its allies—first through development of the DIS protocols and now through the HLA. VV&A is more complex for a distributed simulation than for a unitary simulation since it involves the VV&A of each unitary simulation element (e.g., an HLA federate) and the total distributed simulation (e.g., the HLA federation). Under the leadership of APL personnel, the DIS VV&A group developed the 9-step process noted earlier that has become part of the standard for DIS exercises (IEEE Std 1278.4). The VV&A group of the Simulation Interoperability Standards Organization Simulation Interoperability Workshop, which is chaired by an APL staff member, is developing similar guidance for HLA federations.

Simulation-Based Acquisition

Emphasis on simulation-based acquisition within the defense community[17] as a means to reduce time, resources, and risk associated with system acquisition is another VV&A challenge. Advances in the following capabilities will be needed if the full promise of simulation-based acquisition is to be realized: (1) describe and measure both required and achieved simulation fidelity, (2) determine proper ways to merge information from simulations with different levels of resolution and accuracy, (3) capture (and transform as needed without distortion) information about the subject represented in a simulation so that it can be used as effectively by simulation developers as by reviewers, and (4) capture and store all pertinent simulation V&V information in accessible repositories.

Validation of simulations for which real-world data are limited is particularly challenging, especially when changing paradigms cause historical combat and military exercise data to be of questionable relevance, as is the case for maneuver warfare analysis. JWAD is

developing a conceptual model for maneuver warfare that incorporates human factors and decision making in combat modeling so that morale, fighting spirit, cohesion, and surprise are addressed as well as physical factors such as logistics, sensor and weapon response, etc. The validation challenge is to find, define, or otherwise establish a source of reality that can be used as the standard against which to assess simulation response.

The Laboratory is responding to future VV&A challenges in many ways. APL personnel are involved in DMSO efforts to improve VV&A processes within the defense community. They have leadership responsibilities in developing distributed simulation standards and capabilities. APL personnel are patiently and persistently attending to the hard simulation V&V problems, helping the entire simulation community to make progress in these areas.

REFERENCES

[1]Rich, R. P., "Simulation as an Aid to Model Building," *J. Oper. Res. Soc. Am.* **3**, 15–19 (1955).

[2]Pace, D. K., "A Perspective on Simulation Validation," in *Proc. 1986 Summer Computer Simulation Conf.*, Chicago, IL, pp. 187–189 (1986).

[3]Youngblood, S. M., and Pace, D. K., "An Overview of Model and Simulation Verification, Validation, and Accreditation," *Johns Hopkins APL Tech. Dig.* **16**(2), 197–206 (1995).

[4]Pace, D. K., "Verification, Validation, and Accreditation," Chap. 11, in *Applied Modeling and Simulation: An Integrated Approach to Development and Operation*, D. J. Cloud and L. B. Raines (eds.), McGraw-Hill, New York, pp. 369–410 (1998).

[5]Law, A. M., and Kelton, W. D., *Simulation Modeling and Analysis*, 3rd Ed., McGraw-Hill, New York (1999).

[6]Lewis, R. O., *Independent Verification and Validation: A Life Cycle Engineering Process for Quality Software*, Wiley, New York (1992).

[7]Balci, O., "Validation, Verification, and Testing Techniques Throughout the Life Cycle of a Simulation Study," *Ann. Oper. Res.* **53**, 121–173 (1994).

[8]Balci, O., "Verification, Validation, & Testing," Chap. 10, in *The Handbook of Simulation*, J. Banks (ed.), Wiley, New York, pp. 335–393 (1998).

[9]Knepell, P. L., and Arangno, D. C., *Simulation Validation*, IEEE Computer Society Press Monograph, Los Alamitos, CA (1993).

[10]Pace, D. K., "Conceptual Model Descriptions," in *Proc. '99 Spring Simulation Interoperability Workshop*, Orlando, FL, pp. 133–144 (15–19 Mar 1999).

[11]Pace, D. K., "Development and Documentation of a Simulation Conceptual Model," in *Proc. '99 Fall Simulation Interoperability Workshop* (13–17 Sep 1999), available at http://www.sisotds.org/siw (accessed 28 Feb 2000).

[12]Pace, D. K., "Use of Subject Matter Experts (SMEs) in Simulation Evaluation," in *Proc. '99 Fall Simulation Interoperability Workshop*, Orlando, FL (13–17 Sep 1999) available at http://www.sisotds.org/siw (accessed 28 Feb 2000).

[13]Pace, D. K., "Impact of Simulation Description on Conceptual Validation," in *Proc. '98 Fall Simulation Interoperability Workshop*, Orlando, FL (14–18 Sep 1998), available on CD-ROM and at http://www.sisotds.org/siw (accessed 28 Feb 2000).

[14]Secretary of the Navy (SECNAV) Instruction 5200.40, *Verification, Validation, and Accreditation (VV&A) of Models and Simulations*, (19 Apr 1999), available at http:navmsmo.hq.navy.mil/policy/directives (accessed 16 Feb 2000).

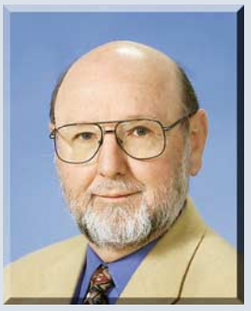
[15]Buchanan, M., "The Heart That Won't Die," *New Scientist* (20 Mar 1999).

[16]Glasow, P., and Pace, D. K. (eds.), "Making VV&A Effective and Affordable," in *Proc. Simulation Validation (SIMVAL) 1999 Minisymposium and Workshop*, JHU/APL, Laurel, MD (26–29 Jan 1999), available at http://www.mors.org/Complete.html (accessed 16 Feb 2000).

[17]Joint Simulation Based Acquisition Task Force, *A Road Map for Simulation Based Acquisition*, Acquisition Council Draft for Coordination, Department of Defense, Washington, DC (4 Dec 1998).

THE AUTHORS

SIMONE M. YOUNGBLOOD received a B.A. in mathematics and B.S. and M.S. degrees in computer science. She has served as the DoD VV&A focal point since 1997 in her position as DMSO's VV&A Technical Director. Leveraging an extensive background in simulation development, modification, and application, Ms. Youngblood has been active in the VV&A community for the past 7 years. She contributed to the Navy's VV&A interim policy guidance and was one of the authors of the initial version (1996) of the DoD *VV&A Recommended Practices Guide*. From 1994 to 1997, she served as chair of the DIS VV&A Subgroup and was co-author and editor of the *IEEE 1278.4 Recommended Practices Guide for Distributed Interactive Simulation—Verification, Validation, and Accreditation*. She has served as chair of the SIW VV&A Forum from 1997 to the present. Her e-mail address is simone.youngblood@jhuapl.edu.



DALE K. PACE is a member of APL's Principal Professional Staff in the Information Analysis Group of the Joint Warfare Analysis Department. He studied mathematics and physics at the University of Chicago (1957–1960), and received a B.D. from Capital Bible Seminary in 1969 and a Th.D. from Luther Rice Seminary in 1974. Dr. Pace is a specialist in operations research, systems analysis, wargaming and seminar gaming, scenario development, and defense analysis. He has been a major contributor to simulation verification and validation ideas and is the Associate Editor for validation of *Simulation*. Dr. Pace also taught in the graduate Technical Management Program of the JHU Whiting School of Engineering from the mid-1980s to the mid-1990s. His e-mail address is dale.pace@jhuapl.edu.

PETER L. EIRICH, a member of the APL Senior Professional Staff, received B.S. and M.S. degrees in electrical engineering from MIT in 1970, an engineer's degree in electrical engineering from MIT in 1974, and an M.S. in management from MIT's Sloan School in 1974. Before joining APL, Mr. Eirich was active in the development of both U.S. and international standards. He has participated on U.S. technical advisory groups, led an international standardization working group on software engineering data, served as the secretary for an international technical committee on design automation, and chaired the subcommittee on EDI and Design Automation (Area 4) of the IEC Advisory Committee on Electronics and Telecommunications. His e-mail address is peter.eirich@jhuapl.edu.

DONNA M. GREGG received a B.S. in mathematics from the University of Maryland in 1984 and an M.S. in mathematics from The Johns Hopkins University in 1988. She joined APL in 1985 as an Associate Staff mathematician and was appointed to the Principal Professional Staff in 1999. She is currently an Assistant Group Supervisor of the Communications Engineering Group in the Power Projection Systems Department, leading the group's efforts in information assurance including M&S of information security (INFOSEC) systems and V&V of INFOSEC models for NSA. Her e-mail address is donna.gregg@jhuapl.edu.

JAMES E. COOLAHAN has been the Assistant to the Director for Modeling and Simulation at APL since 1996. He received a B.S. in aerospace engineering from the University of Notre Dame in 1971, an M.S. in the same discipline from the Catholic University of America in 1975, an M.S. in computer science from The Johns Hopkins University in 1980, and a Ph.D. in computer science from the University of Maryland in 1984. Since joining APL in 1972, Dr. Coolahan's technical activities have included M&S, test and evaluation of missile systems, and the development of oceanographic data acquisition systems. He served as the Program Manager of the Ocean Data Acquisition Program (1982–1990), Supervisor of the System Development and Evaluation Branch of the Strategic Systems Department (1988–1990), and Program Area Manager of the Space Systems and Technology Applications Program Area (1990–1996). His e-mail address is james.coolahan@jhuapl.edu.