**VERIFICATION AND VALIDATION:**

# WHAT IMPACT *SHOULD* PROJECT SIZE AND COMPLEXITY HAVE ON ATTENDANT V&V ACTIVITIES AND SUPPORTING INFRASTRUCTURE?

**Panel Presentation**


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## ABSTRACT

The size and complexity of Modeling and Simulation (M&S) application continue to grow at a significant rate. The focus of this panel is to examine the impact that such growth *should* be having on attendant Verification and Validation (V&V) activities. Two prominent considerations guiding the panel discussion are:

(1) Extending the current M&S development objectives to include quality characteristics like maintainability, reliability, and reusability -- the current *modus operandi* focuses primarily on correctness, and
(2) Recognizing the necessity and benefits of tailoring V&V activities commensurate with the size of the project, i.e., one size does not fit all.

In this paper we provide six questions and four sets of responses to those questions. These questions and responses are intended to foster additional thought and discussion on topics crucial to the synthesis of quality M&S applications.


## 1 INTRODUCTION

The following observations motivate and "set the stage" for needed change in the way the we approach M&S development:

(a) Both the size and complexity of M&S applications are growing,
(b) The domains of application within industry and DoD continue to expand,
(c) The larger M&S projects are requiring increased levels of involvement of people with diverse capabilities and background, e.g. software engineers, domain experts, and M&S personnel, and
(d) The expected lifetime of M&S applications is continually increasing.

If we believe that the above observations are valid, then we must also begin to recognize and address the new demands they place on M&S development activities. Prominent among them is the increased role of *verification* and *validation* within the M&S lifecycle. The issues outlined below stem from the above observations and will form the basis for our panel/audience discussion.

## 2 POSED ISSUES AND QUESTIONS

In support of the objectives and expectations of the panel session, each panel member was asked to reflect and comment on the following set of issues.

### Issue 1: Changing the Culture - Getting Management's Buy-in

Clearly, as the size and complexity of M&S applications grow, so does the need for V&V. What does this mean for those development companies that have no (or minimal) V&V infrastructures? In any organization an *effective* V&V operation must be initiated from the top down. That is, management must be one of the primary supporters. At issue here is (1) how do we educate management on the importance of V&V, and (2) how do we get management to provide the necessary resource to implement effective V&V. Two difficulties are readily apparent: getting management to set aside time for their own "education", and relating the benefits of V&V in terms that management understands, i.e., cost savings and a better product.

**Issue 2: Moving Toward an M&S Development Environment**

The prevailing "wisdom" seems to be: "give me tools, tools, tools." That is, to help combat the complexities of today's M&S application domains, practitioners are asking for more tools to support M&S activities. Clearly, the need for tools to support the development effort is real. Moreover, that need continues to increase with the size and complexity of proposed systems. Unfortunately, the request for tools is being made blindly, without any forethought as to which (if any) underlying development principle(s) the tools should support. Additionally, these tools are being thought of as stand-alone instruments, without any consideration as to how they might works together to support development across phases. Is it time that we begin to examine the benefits of a development *environment* providing a unified set of tools? Should we also begin to focus on the evolution of methodologies that support the development of quality M&S applications using recognized principles to achieve desirable objectives?

**Issue 3: Emphasizing Quality of the Product**

Currently, there appears to be an over-preoccupation with establishing correctness, primarily through validation. This is reflective of the mindset that "all I want is for the simulation to work correctly." However, correctness is but *one* of the quality characteristics that we should be striving to achieve. Is it time to move beyond our preoccupation with this one characteristic? Do new development objectives require a re-thinking of what are desirable product characteristics? Clearly, as M&S applications are built with extended lifetimes in mind, maintainability must be one additional consideration. Reliability, reusability and adaptability are other quality characteristics. Within M&S do we view these additional characteristics as desirable? If so, how do we build them in and at what price? At issue here is recognizing (a) *what* constitutes quality, (b) *why* would we want to build it in, and (c) *how* do we build it in.

If the definition of product quality is expanded to include, in addition to correctness, other desirable characteristics, should we also consider a formal Quality Assurance process separate from (but complementing) the development activity? If so, what does this mean in terms of V&V responsibilities for the development group?

**Issue 4: Establishing Higher Confidence Levels through Field-Testing**

The increasing size and complexity of problems being addressed by the M&S community is causing a substantial increase in the effort required to field-test corresponding simulation models. That increased effort translates into additional costs. Consequently, there is an emerging sentiment to forego the expensive field-testing and to rely on synthetic data to validate our models. To what extent can synthetic data suffice as a proxy for field data? Can we validate with synthetic data alone? Are there system characteristics that obviate (or mandate) the need for field-testing? How would the reduced use of field data in validating a simulation model impact our confidence level? What criteria might we use to judge the extent to which we sacrifice field-testing for costs?

**Issue 5: Resolving the Differences in Definitions of Verification and Validation**

Systems are currently under construction that require multiple simulation models and supporting software. The development of such systems requires the collaboration of a diverse set of people from industry, DoD and academia. Unfortunately, all three groups appear to have their own definitions of Verification and Validation. Working toward a common goal requires that all groups "march to the beat of the same drummer," that is, use common definitions. Why have different definitions evolved? Is there really a need for a set of common definitions? If so, what are the impediments to moving toward a unifying definition for verification and one for validation?

**Issue 6: Does "One Size Fit All"**

In the past M&S development models have varied significantly in the extent to which they emphasize and incorporate V&V activities. In response to the growing size and complexity of M&S applications, however, current M&S models are focusing on incorporating a full set of V&V activities and mandating their use within a rigid framework. But, does "one size fit all?" Are the V&V process requirements the same for large- and small-sized projects? What impact would the requirement for extensive V&V have on small companies that currently produce high-quality M&S applications? Is the tailoring of the V&V process and activities a viable option? Can a tailored process (perhaps incorporating a subset of "required" activities) still produce a quality product?

## 3 PANEL RESPONSES

### 3.1 Responses of James B. Dabney (Software Engineer, V&V)

Issue 1: *Changing the Culture - Getting Management's Buy-in*

In my experience, the biggest problem is not getting upper management interested in V&V, it is getting middle management interested. There is a real resistance on the part of middle managers, caused mainly by reluctance to lose control and a concern about losing credibility if issues are identified. Upper management is less worried about these issues and more worried about mission failure. They are happy to have issues identified and don't lose face or credibility. So, the only successful strategy is to introduce V&V to upper management first and have them mandate it for the organization.

I believe that the crucial motivator for upper management with respect to V&V, and in particular IV&V, is mission failure. I have been doing IV&V for ten years, and I still don't have adequate verifiable evidence to prove that IV&V saves you money or even improves quality. I know it does both, but I can't prove it. Fortunately, I don't have to prove it. CEOs, federal agency directors and military leaders all understand that a critical software failure will end their enterprise, and showing them that V&V can reduce the chance of a critical software failure seems to be enough these days.

The education problem with respect to upper management seems not to be *do we need it*, but *how much is it going to cost*. My experience has been that upper management frequently has unrealistic expectations concerning V&V resource requirements. I have observed this on all sizes of projects – from a 10 person manufacturing company to large NASA projects. In every case, there is a real sticker shock problem. For example, I was recently asked to perform comprehensive IV&V on a product with ~100,000 lines of code, developed by ~25 programmers and engineers over a period of several years using one engineer, half-time, for 4 months. So from my perspective, the most pressing issue today is to develop reliable V&V cost models backed up by solid data.

Issue 2: *Moving Toward an M&S Development Environment*

The biggest problem I have observed with respect to tools is the lack of standardization, particularly on large projects. For example, on one large near-real-time simulation and design project, there were four distinct developer groups, all working for the same target computer and operating system, but for different application domains. All were required to use the same compiler, but each had its own toolset, some commercial and some built in-house. The four groups used four tools for GUI development and three CM tools.

This project made clear that it is mandatory for project management to design an M&S project from the top down. The consequences of allowing independent groups to form an ad hoc confederation are lots of rework, lots of interface kludges, and very weak CM. So your conjecture that a unified development environment is beneficial seems to me to be too modest. I am of the opinion that development environment requirements and design have become as important as functional requirements and design.

Issue 3: *Emphasizing Quality of the Product*

Software quality assurance, in every project with which I'm familiar, has been uniformly ineffective. I believe that this is because it was based on a manufacturing quality assurance model that simply does not apply to software development. A software quality assurance activity might be useful, but its role needs to be rethought.

Certainly, all software quality factors are important for M&S software. I believe that the only way to ensure that these factors are present in the software is to plan for them from the outset. The most important of these from my perspective is maintainability, which results from a strict adherence to a software development lifecycle and a strict adherence to coding standards.

An additional note on this topic is that it is very difficult to establish correctness in software that is of low quality.

Issue 4: *Establishing Higher Confidence Levels through Field-Testing*

For most simulations of spacecraft, extensive use of synthetic data is necessary. Field testing usually must be performed in conjunction with operational missions. In many cases, field data is available from previous missions, but the coverage available from the field data is limited and usually does not include failure scenarios. However, experience has shown repeatedly that every effort must be made to conduct as much field testing as is possible. Real-world data is frequently full of surprises.

Synthetic data requires a second level of verification and validation. It is also necessary to perform V&V on the synthetic data.

In my role as a user of military battle simulations for battle staff training, I have repeatedly encountered the difficulties associated with insufficient field testing. Unexpected (frequently incorrect) user inputs, larger than expected databases, and new weapons systems and operational scenarios have all caused costly simulation crashes. As the use of M&S in military training increases, the cost of simulation crashes will continue to rise.

Issue 5: *Resolving the Differences in Definitions of Verification and Validation*

My experience with V&V has been focused on NASA software. Even within NASA, there is great diversity as to the definitions of V&V. However, this diversity has not been a significant problem.

Issue 6: *Does "One Size Fit All"*

I have not been exposed to the "one size fits none" dilemma in V&V specification and application. Our standard IV&V process starts with a tailoring activity to adapt a set of baseline activities and tools to the development process at hand. I believe that an attempt to mandate a rigid V&V approach to projects of different sizes and using different development styles would be very inefficient and ineffective.

### 3.2 Responses of Averill M. Law (Modeling & Simulation, Industry)

Issue 1: *Changing the Culture - Getting Management's Buy-in*

In my experience, decision-makers (or managers) often do not have a good understanding of simulation, the resources required, and their role in a successful simulation project. In order to produce a valid simulation model that is actually used in the decision-making process, it is imperative that the decision-maker be involved in problem formulation and also understand and agree with key model assumptions. The reason for model validation should be clear. A simulation model is a surrogate for making decisions by experimenting with the actual system, which is usually not cost-effective or feasible. Therefore, if the model is not "valid," any decisions made with the model are likely to be of limited value.

Issue 2: *Moving Toward an M&S Development Environment*

In my experience, many organizations that do simulation for their own use or under contract for a client devote little time to validation or to the statistical aspects of simulation. In many cases, simulation is viewed largely as a complicated programming exercise. Perhaps, seventy-five percent of the people who perform "simulation studies" only have training on how to use a simulation software product, which is totally insufficient. Thus, *both* the analysts and the managers need to be better educated. Managers should attend a one-day seminar that discusses what is simulation, what can it do for them, the steps in a sound simulation study (including validation techniques), and management's role in a successful project. Analysts should be required to attend a three- to five-day seminar on simulation methodology (if they are not already familiar with the necessary concepts and techniques).

Issue 3: *Emphasizing Quality of the Product*

Most simulation models built for the Department of Defense (DoD) are reused a number of times over a period of years. Thus, it is imperative that these models be well documented – it is not sufficient to have a few "random" comments in the simulation program. There needs to be a detailed document that describes model assumptions and data. It should be mentioned that in the industrial/commercial world, models are often only used on a one-time basis.

Issue 4: *Establishing Higher Confidence Levels through Field-Testing*

In general, the most definitive technique for validating a simulation model is to compare performance measures produced by the model with the comparable performance measures from an existing system (if one exists). For industrial models, this is often accomplished by collecting data from an existing system (e.g., a factory). The model is first configured to represent the existing system for purposes of performing the validation comparison. Once the model is determined to be "valid" for the existing system (if ever), then the model is configured to represent the system configurations actually of interest. In general, it is not possible to validate completely a model of a system that does not currently exist.

In the DoD community, the aforementioned validation comparison is often accomplished by field testing a prototype weapons system in order to collect system data. If this step is skipped (assuming that it is feasible) in order to save money, then the model may not be "valid" and its use may produce erroneous results.

Issue 5: *Resolving the Differences in Definitions of Verification and Validation*

I believe at the present time that most people understand the difference between validation and verification. The real question is how do we perform model validation in practice. Based on performing approximately forty simulation projects, I believe that model validation involves mostly subjective techniques (e.g., a structured walk-through of the model assumptions before programming) rather than the use of formal statistical techniques.

Issue 6: *Does "One Size Fit All"*

Most industrial organizations do not use a formal structure for model validation. For example, model accreditation (which is mandated within DoD) is not explicitly used in most companies. In practice, there are really only a small number of validation techniques that are available (probably ten or less), regardless of the size of the modeling effort.

### 3.3 Responses of John D. (Jack) Morrison (Modeling & Simulation, DoD)

Issue 1: *Changing the Culture - Getting Management's Buy-in*

To get management to buy into V&V, the community needs to relate specific Verification and Validation products to specific management and model development decisions. I wrote the following comments to this affect for the DoD Simulation Validation conference report. *While the general analytical method is straightforward, the science, mathematics, and statistics communities have not yet produced a truly comprehensive theory for quantify prediction uncertainty in simulations. For that reason, the comparison step in model validation remains largely qualitative (face validation) and ad-hoc. Because of difficulties with knowledge elicitation and conceptual modeling (see paragraph 5 below), this practice leads further increases in uncertainty about subjective judgements as well as increased cost. Although a comprehensive theory remains elusive, DMSO continues to monitor and support the relevant research to ensure that as formal methods mature, they are incorporated into DoD's recommended practice so that the following user questions can be answered.*

- *To what extent does a model preserve what is known and not known about this domain?*
- *Was the underlying uncertainty in the database preserved?*
- *What modifications to the model would produce the most significant impact on its prediction uncertainty (relates to the user's decision risk management)?*
- *Are there simpler model designs that have relatively equivalent levels of prediction uncertainty (relates to the user's cost management)?*

I can discuss specific methods, derived from the model uncertainty literature, that can be used to answer these questions in quantitative terms. Additionally, the community needs to develop more specific and detailed cost models that incorporate the cost of getting it wrong. Managers need these models to make deliberate decisions that relate V&V cost with benefits in practical ways.

Issue 2: *Moving Toward an M&S Development Environment*

While it is well recognized that a comprehensive and accepted methodology for validation of models does not yet exist, I would posit that one does not exist for verification either. While a large number of tools and techniques exist for doing things that we relate to verification, it is not clear to me that an integrating methodology exists. By that I mean, how does one take all of the information that might be collected in the name of verification, and integrate it into a single metric? To that end, I provide additional information from the SIMVAL Report. *With respect to verification, while the causes are different, the implication is the same – the user community is rarely provided a comprehensive and coherent metric that characterizes the overall reliability of the computational model (hardware and software). Rather, verification reports generally provide voluminous information about independent analyses on the various software development activities (requirements, design, software development, and implementation testing). While these reports are often useful for developers, they are rarely understandable, let alone useful, for the user. There are two general reasons for this: first, comprehensive methods do not currently exist; and second, software quality assurance standards are predominantly process- versus product-based. Specifically, user requirements for model verification are different from industry standards for SQA. While the SQA literature provides many techniques that can be used to quantify software reliability, there is a tendency for the model development community to equate SQA practice with model verification. They are two different things. SQA is a program management activity that is related to producing the required product on time and within budget. SQA is not an explicit VV&A task and should not be budgeted to VV&A. DoD practice for verification needs to keep this difference in mind as a basis for reassessing its standards and practices for verification reporting and costing.*

Issue 3: *Emphasizing Quality of the Product*

I am not in a position to comment about metrics for verification, but I am for validation. The term ***validation*** is widely used by the modeling community to characterize the quality of model predictions relative to what is known about the real world. Model validation is typically discussed in a binary sense -- a model is either valid or invalid. This view of validation is based on the implicit assumption that the behavior of the physical world is well understood. In fact, our understanding of the world is never complete (causing it to appear unstable and inconsistent) and is always based on experiences that never generalize, with complete accuracy, into the future. Consequently, the predictions produced by models always incorporate some likelihood of being wrong. Therefore, more comprehensive definitions of validity treat the relationship between model predictions and reality in a more continuous sense, referred to as ***prediction uncertainty***. These definitions provide a basis for comparing model designs relative to the quality of the predictions that they produce for a particular class of problems. I address validation in this broader context.

Issue 4: *Establishing Higher Confidence Levels through Field-Testing*

Our model validation research is conducted within a statistical framework for conducting computer experiments. This framework incorporates the following notions. In model validation, it is important to understand that there are two sources of variability that contribute to uncertainty in prediction:

- one, is a characteristic of a particular MOE and level of model aggregation -- $\sigma_y^2$;
- the other is characteristic of a particular domain and set of observations -- $\sigma_\omega^2$.

Therefore, the ability to validate a model (to determine the magnitude of $\delta$) is influenced by both the amount of variability in the model's output, $\sigma_y$, and the referent data, $\sigma_\omega$. Interpreting the variance as the noise component of a signal-to-noise problem, model validation requires management of both sources of noise. While discussions of model validation tend to focus on the variability due to model aggregation (characteristics of *y*), the variability in the data (real world observations -- $\sigma_\omega$) is also a proper component of an accurate model prediction. Therefore, when this variability contributes to a level of prediction uncertainty that is unacceptable, the appropriate remedy is improved data collection. Because we use these parameters as the basis for understanding the relationship between data collection (including knowledge elicitation) and model development, we refer to the associated statistical techniques as ***variance-based methods***. In summary, once a model design is well-correlated ($\rho_{y\omega} \approx 1$), correctly centered ($\mu_y$-~$\mu_\omega$), and properly scaled to the existing data ($\sigma_y \approx \sigma_\omega$), then the remaining prediction uncertainty can only be reduced by collecting new data from the domain of interest. Interestingly, when appropriate methods are used to conduct uncertainty analysis on the model, they can isolate the processes (model variables) and information characteristics that exert the greatest influence on $\sigma_\omega^2$ – they can tell us what information will contribute most effectively to reducing the model's prediction uncertainty.

Issue 5: *Resolving the Differences in Definitions of Verification and Validation*

I think this has been resolved by IEEE.

Issue 6: *Does "One Size Fit All"*

Uncertainty analysis provides a basis for relating specific aspects of the data (cost of field trials), abstractions (cost of modeling), and prediction uncertainty. They allow a user to map decisions directly to reliability and risk.

### 3.4 Responses of Robert G. Sargent (Modeling & Simulation, Academia)

Issue 1: *Changing the Culture - Getting Management's Buy-in*

One approach is to develop a short write-up (at most a few pages) that can be given to managers. This write-up should be easy to read and such that a manager can put it into their briefcase to take home. Such a write-up should explain what Verification and Validation (V&V) are, why V&V are important, why top management should support V&V, and why sufficient resources should be allocated to V&V.

Issue 2: *Moving Toward an M&S Development Environment*

Modeling and Simulation Development Environments are desirable. However, this is not a simple issue. Small simulation projects and entry level analysts require simple and easy to use environments. Large and complex simulation projects require environments with considerable capability to assist the analysts as well as provide information for management. Different types of model development methodologies and different types of supporting infrastructures will probably required different environments. Much research is needed on this issue.

Issue 3: *Emphasizing Quality of the Product*

This panelist believes that quality attributes (such as model "correctness and accuracy", reliability, and reuse) are currently being considered in most modeling and simulation projects. However, the approach is formal for some attributes (such as model correctness and accuracy) and informal for other attributes (such as software maintainability). For large simulation projects a formal approach should be taken for most or all of the quality attributes and thus a change is required for the large projects.

Issue 4: *Establishing Higher Confidence Levels through Field-Testing*

This panelist believes that several sets of real world data are required for model validation in order to obtain high confidence in a model. Synthetic data alone is NOT sufficient for model validation. Validating models is expensive and support must be provided for it. Unfortunately, modeling and simulation is currently being sold by some people as a way to avoid field testing in order to save money. Simulation can help in numerous applications (such as training) to save money but the basic simulation models themselves need to be validated using real world data which in part come from field tests.

Issue 5: *Resolving the Differences in Definitions of Verification and Validation*

Different definitions for verification and validation are not surprising since simulation and computing are young fields. Within the discrete event simulation field most definitions are not vastly different; however, when one goes to different types of simulation and software engineering then different definitions do occur. It would be nice to have common definitions across the different fields and this panelist believes that this will occur over time. As large scale projects occur and people from different fields work together common definitions will develop naturally.

Issue 6: *Does "One Size Fit All"*

This panelist does not believe that one V&V approach fits all sizes of simulation projects. Different size simulation projects require different supporting infrastructures, different types of personnel, and different methodologies. Small projects require only a single analyst while large projects require several groups of different types of analysts. In large projects the various quality attributes need to be addressed formally while for small projects some attributes should be addressed informally.

## AUTHORS BIOGRAPHIES

**JAMES D. ARTHUR** is an Associate Professor of Computer Science at Virginia Tech (VPI&SU). He received B.S. and M.A. degrees in Mathematics from the University of North Carolina at Greensboro in 1972 and 1973, and M.S. and Ph.D. degrees in Computer Science from Purdue University in 1981 and 1983. His research interests include Software Engineering (Methods and Methodologies supporting Software Quality Assessment and IV&V Processes), Parallel Computation, and User Support Environments. Dr. Arthur is the author of over 30 papers on software engineering, software quality assessment, IV&V, and user/machine interaction. He has served as: participating member of IEEE Working Group on Reference Models for V&V Methods; Chair of Education Panel for National Software Council Workshop; Guest Editor for *Annals of Software Engineering* special volume on Process and Product Quality Measurement; and Principal Investigator or Investigator on 15 externally funded research projects totaling in excess of $1.5 million. Dr. Arthur is a member of Pi Mu Epsilon (Math Honor Society), Upsilon Pi Epsilon (Computer Science Honor Society), Golden Key National Honor Society, Sigma Xi (National Research Society), ACM, and the IEEE Computer Society.

**JAMES B. DABNEY** received the B.S. in Mechanical Engineering from Va. Tech, the M.S. from University of Houston, Clear Lake, and the Ph.D. from Rice University. He has been involved in IV&V of mission critical systems for nine years, working on Space Shuttle and International Space Station onboard flight software and critical ground-based software projects. He is currently a Lecturer on Mechanical Engineering at Rice University and a consultant to AverStar, Inc. of Houston, TX. His research interests encompass IV&V, process control and optimization, and computer aided engineering. Dr. Dabney can be contacted at AverStar, Inc., 1100 Hercules, Suite 300, Houston TX, 77058. His e-mail address is jdabney@rice.edu; his telephone number is (281) 480-4101.

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**JOHN D. (JACK) MORRISON** has a Ph.D. in Computer Science and Psychology as well as an M.S. in Industrial Engineering (Operations Research). He has over 25 years of military, government, commercial, and academic experience in modeling, analysis, and testing of military systems. He has a unique background in the integration of machine learning and computer simulations for the development of optimum control strategies, or tactics, for complex and competitive spatio-temporal environment. That research resulted in a number of journal publications within the operations research literature as well as award of the Military Operations Research Society's annual Barchi Prize in 1991. Jack's recent focus is on developing and applying statistical methods to the formal design and evaluation of computer models in general and defense deployment simulations in particular.

**ROBERT G. SARGENT** is a Research Professor/Professor Emeritus at Syracuse University. He received his education at the University of Michigan. Dr. Sargent has served his profession in numerous ways and has been awarded the TIMS (now INFORMS) College on Simulation Distinguished Service Award for longstanding exceptional service to the simulation community. His research interests include the methodology areas of both modeling and discrete event simulation, model validation, and performance evaluation. Professor Sargent is listed in *Who's Who in America*.