INDEPENDENT VERIFICATION AND VALIDATION: A MISSING LINK IN SIMULATION METHODOLOGY?

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ABSTRACT

Independent verification and validation (IV&V) is a powerful tool that can be used to mitigate the increasing complexities associated with an ever-expanding set of modeling and simulation problems. In this paper we discuss the use of independent V&V within the modeling and simulation community. Literature reviews and conversations with experienced technical managers serve as a basis for our conjecture that (a) validation is the major focus of most modeling and simulation efforts, (b) verification plays only a secondary role, and (c) independent V&V is, for all practical purposes, being ignored. In an effort to raise the awareness of the benefits and applicability of independent V&V within the modeling and simulation community, we describe in a step-by-step fashion the application of independent V&V to one particular life cycle model of a simulation study.

Keywords: Verification, Validation, Independent V&V, Model Verification, Model Validation, Modeling and Simulation, V&V Activities, V&V Benefits

1 INTRODUCTION

Because this paper discusses IV&V as it relates to both software engineering and modeling and simulation, we present definitions of verification and validation based on those found in (Balci 1994). In general, validation is the process of substantiating that the behavior of a model or software system conforms to stated requirements. In the modeling and simulations domain, those requirements are derived from the objectives of the simulation study. Verification, on the other hand, is the process of substantiating that each successive model or software system representation is transformed from one form into another, as intended, with sufficient accuracy. In effect, validation deals with building the *right* model or system; verification deals with building the model or system *right*.

Within the software engineering community the complexity of today's systems is dictating the need for and expanded use of *independent* verification and validation (IV&V). Although standard "in-house" V&V techniques are used during many software development activities, their effectiveness and potential to achieve maximal benefits are often constrained by:

- organizational objectives and concerns, and
- an inability of developers to perform critical analyses without being influenced by their active participation in the development effort.

The discrete event modeling and simulation (M&S) community shares similar goals, and impediments to achieving those goals, in their quest to build simulation models and related software systems (e.g., retrospective analysis, animation generators, etc.) that accurately reflect real-world interactions. Clearly simulation software exhibits similar complexity and criticality characteristics as found in non-simulation software. *Why then does there appear to be no movement, or desire, to introduce independent V&V into the M&S development process?*

While it is not our intent to answer the above question, we do pose it to express a concern and to promote *independent* V&V as an additional "tool" to help cope with the growing demand of increasingly complex simulation studies. In doing so, this paper focuses on substantiating the perceptions that IV&V is being ignored and outlining the potential use and benefits of IV&V in the M&S community.

2 INDEPENDENT VERIFICATION AND VALIDATION: AN OVERVIEW

2.1 Definitions and Objectives

From the software engineering perspective, Lewis (Lewis 1993, p. 7) defines verification as an iterative process aimed at determining whether the product of each step in the development cycle:

- fulfills the requirements levied on it by previous steps, and
- is internally complete, consistent, and sufficiently correct to support the next phase.

Validation, on the other hand, is defined as the process of executing the software to exercise the hardware and comparing the test results to the specification requirements.

An examination of the above definitions reveals that both verification and validation strongly correlate with those definitions found in the simulation literature (Caughlin 1995, Balci 1994). In particular, M&S software is validated relative to perceived or actual systems behavior, while verification is the activity that ensures that the simulation software accurately reflects the model.

Independent Verification and Validation is defined as a series of technical and management activities performed by someone other that the developer of a system with the objectives of

- improving the quality of that system, and
- assuring that the delivered product satisfies the user's operational needs.

While not totally absent in the simulation literature, see for example (Sargent 1994), references to independent V&V in the simulation literature are rare indeed.

The advantages of an independent IV&V process are many. In particular, the *independence* in V&V

- provides an objective assessment of the product during its creation,
- adds a new analytical perspective not present in the development environment,
- brings its own set of tools and techniques to bear on ensuring development accuracy and validity,
- introduces "intermediate" users of the system who serve as "beta testers" before the product goes to market, and finally
- significantly enhances testing and the discovery of design flaws and coding errors.

2.2 IV&V in the Software Development Life Cycle

Within the conventional software development life cycle, independent V&V is best illustrated in Figure 1.

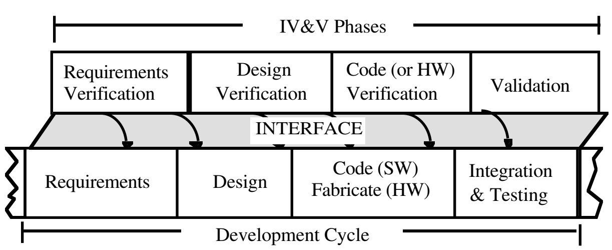

Figure 1: IV&V Interface with Development Cycle

Each of the verification phases and the concluding validation phase begins as soon as possible after initiation of its development counterpart. Development artifacts are examined through phase-specific V&V activities; results of those examinations are then factored back into the development process. In an independent V&V scenario, the organization performing the V&V activities is not part of the development organization. The interface between the development and IV&V organization is defined in a contractual agreement stipulated by the sponsoring organization.

Achieving effectiveness in an independent V&V effort requires that its integration with the software development effort be:

(1) viewed as an overlay process that is *separate* and *distinct* from the development effort,
(2) designed to complement the software development effort and to minimize any adverse impact on the development schedule, and
(3) tailored to fit the application and, as much as possible, the development organization's software development process.

3 INDEPENDENT VERIFICATION AND VALIDATION IN MODELING AND SIMULATION

Clearly we believe that independent V&V is not only desirable, but has much to offer the M&S community. An examination of current literature reveals that V&V is an integral part of most modeling and simulation efforts, but also tends to confirm our suspicions that the use of *independent* V&V methods is severely lacking. We outline the results of that investigation as it relates to the treatment of independent V&V in "theory" and in practice.

3.1 Treatment in Theory

The first part of our investigation focuses on determining the role that *independent* V&V plays in the theoretical domain. That is, we focus on the extent to which IV&V is being touted in simulation texts and research papers emphasizing simulation methodologies. The selected texts focus on topics ranging from simulation modeling and analysis, to those that stress the instruction of simulation methods. The publication dates spanned the time period from 1987 through 1993. Within that group, four of the books lack any treatment of V&V (Cassandras 1993, Karian and Dudewicz 1990, Schruben 1992, Zeigler 1990); three of the remaining four books provide only a cursory introduction to V&V (Bratley, Fox and Schrage 1987, Davies and O'Keefe 1989, Ross 1990), and only one devotes multiple sections to V&V (Law and Kelton 1991). Not surprisingly, none of the eight text books addressed independent verification and validation.

An examination of the last four proceedings from the Winter Simulation Conference (WSC) and several back issues of *Transactions on Modeling and Computer Simulation* (TOMACS) reveals that many researchers are aware of the necessary role that V&V plays in model development and simulation. Although we found no papers in TOMACS that had V&V as its major focus, several were present in the WSC proceedings, e.g. (Caughlin 1995, Sargent 1994, Balci 1994, Kleindorfer and Ganeshan 1993, Pace 1993, Yucesan and Jacobson 1992, Bailey and Kemple 1992, and Legge and Wyatt 1992). Each paper reiterates the critical need for V&V; several of them describe new and extant methods for implementing V&V practices. Only one author, Sargent (Sargent 1994), advises the use of independent V&V to address the growing complexity of simulation software. More specifically, he states that independent V&V is usually applied to large-cost simulation studies and is most effective when applied during the development process.

3.2 Treatment in Practice

The second aspect of our investigation examines the extent to which independent V&V is being used in practice. Two sources of information are considered: published papers describing practical applications of M&S, and persons actively involved in developing or managing M&S efforts. Papers describing the application of M&S to problems found in industry and government abound in the WSC proceedings. During a cursory examination of several papers, we noted that most of them describe some form of verification and/or validation activities. We then selected eight papers at random to review more closely. We observed that seven of the eight describe some form of verification or validation: two on verification and validation efforts, four on validation only, and one on verification efforts only. Not surprisingly, validation assumes a prominent role in the development of simulation models and software. Verification appears to be relegated to a lesser role. Unfortunately again, we found no papers describing independent V&V being applied to the development of the simulation models and software.

As a final data point we discussed the role of IV&V with a technical manager possessing 25 years of experience working with major DoD software systems, including simulations. His position is that independent V&V should be included as part of the development effort, but in most cases it is not. He further states that one need not necessarily employ an independent organization to perform the V&V. We note that this manager's primary experience with simulation modeling is to produce "scaffolding software" for testing embedded systems software under development. Thus, the developed software is tested by a "simulator/stimulator" that initiates the interfaces needed with the remainder of the system in which the developed system is embedded. Within this type of framework, independence is gained if one group develops the embedded software, one group develops the stimulator/simulator, and a third party provides the real-world data to validate interaction of the two. In reality, however, this approach achieves only independent validation and misses out on those benefits attributed to independent verification, e.g., early error detection and reduced effort to fix those errors.

3.3 In the Final Analysis

Based on the analysis outlined above we conclude the following:

(1) Validation is "alive and well." Most simulation developers are aware of and attempt to validate their models and products relative to real-world expectations.
(2) Verification plays a secondary role in the development process. That is, the prevailing wisdom is that validation is the crucial hurdle and little benefit is recognized in employing verification to assure the desired outcome of the validation process.
(3) *Independent verification and validation is being ignored.*

Why is there such a stratification in the level of use among validation, verification and independent V&V? Clearly, validation is deemed crucial in showing that one's simulation model and software system adequately reflects the behavior of the system under study. We believe that verification plays a reduced role because of the additional costs in terms of time and effort. Moreover, there is some truth to the prevailing wisdom stated in (2) above. Yet, what is the recourse when no real system exists to produce observable behavioral data? We believe that the subjective techniques described in (Balci 1994) must be buttressed by meticulous attention to verification.

Finally, why is the use of independent V&V totally lacking in development efforts encompassing M&S? The circumstances outline below offer some assistance in answering this question.

- The costs and benefits of independent V&V must be judged relative to the size, complexity and critical nature of the product being developed. Because simulation models and systems have exhibited only modest growth in size and complexity over the last years, the demand for independent V&V has not been justifiable.
- Even for those sizable development efforts where independent V&V can produce cost savings, the entrenchment of existing M&S procedures hinder the introduction of new approaches.
- Finally, the real benefits of independent V&V and risk mitigation (i.e., balancing IV&V costs against derived benefits) are only now beginning to surface. This has contributed to the perception that IV&V is

cost prohibitive and to a lack of real understanding as to why, when and how IV&V should be employed.

4 THE BENEFITS OF INDEPENDENT VERIFICATION AND VALIDATION

Underscoring the increasing importance of verification and validation, Caughlin states that "as our ability to model the real-world grows, our ability to verify or validate these models shrinks" (Caughlin 1995, p. 1405). While his proposal to use reduced order metamodels is appealing, we question the extent to which additional detail can be hidden without sacrificing critical information.

4.1 Placing IV&V in Perspective

In "bottom line parlance" we must recognize the necessity and importance of both verification and validation, and be prepared to expend the requisite effort to adequately perform such activities. As noted in Section 3.3 validation is receiving proper attention. Minimally, one should expect validation to be performed because its results confirm the validity of the model and simulation system. On the other hand, verification (i.e., establishing correctness between the model and simulation) appears to be somewhat lacking. As M&S problems grow in size and complexity, the role of verification becomes even more critical. More specifically, the more complex a system is, the higher the probability of introducing an error during development. Verification stresses the early detection of errors, which in turn, translates into reduced development costs and reduced schedule slippage.

In discussing the benefits of independent V&V we first make the following assumptions:

- The problem being addressed is of sufficient size and complexity to warrant the use of independent V&V. In part, this assumption is driven by the fact that the additional costs imposed by IV&V must not be prohibitive. Lewis (Lewis 1993) states that an IV&V effort should be allocated 16%-17% of the development budget. This translates to 3%-4% of the life-cycle costs.
- The model and simulation software is being developed for a customer who is not affiliated with the development organization. In large organizations, however, the customer might be employed by a branch of the organization different from the development branch.
- The IV&V organization possesses expertise in both simulation and the application domain.
- Verification and validation play equally important roles in the M&S development process.

4.2 The Activities and Derived Benefits

To place our discussion in context, we examine the advantages of independent V&V relative to the life-cycle model defined by Balci and Nance (Balci 1994, Nance 1994). That model is illustrated in Figure 2.

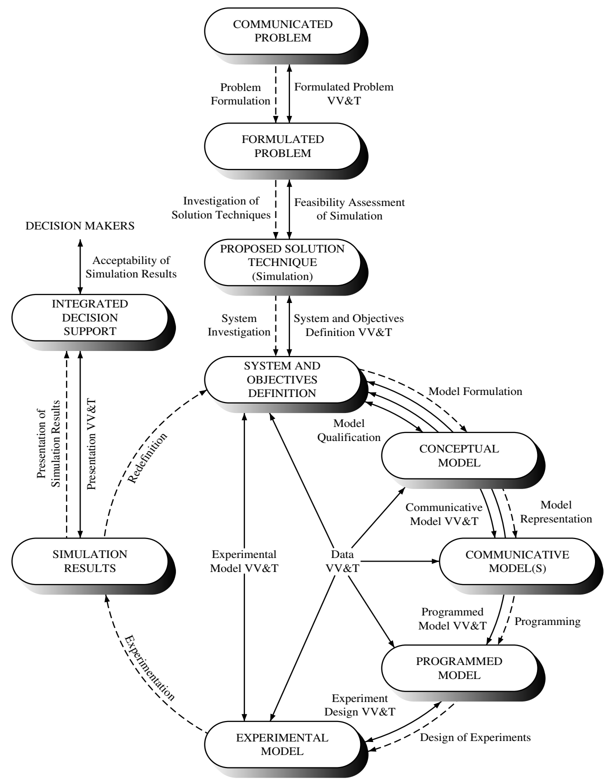

Figure 2: The Life Cycle of a Simulation Study

The first three steps address problem identification, formulation and the feasibility of using simulation in defining a solution. In effect, these activities capture the critical characteristics of the problem and determine to what extent simulation provides a viable solution approach. The independent agent contributes to the process by:

- acting as an "interpreter" between the customer and developer, and thereby minimizing the possibility of mis-communication,
- providing an additional perspective on the problem, and thereby, complementing and augmenting problem identification and formulation,
- recording decisions and details to ensure that they are reflected in the proposed simulation solution,
- contributing to the proposed solution through suggested approaches and alternatives, and
- providing an independent feasibility assessment.

Transitioning from the Proposed Solution Technique (step three) to System and Objectives Definition (step four) is most crucial because it is during this process where the requirements for the model and simulation system are defined. Correspondingly, the responsibilities of the independent agent include:

- verifying that the evolved requirements accurately reflect and address
  - (a) the critical characteristics of the formulated problem, and
  - (b) the proposed solution approach,
- providing feedback to the developer when discrepancies are detected, and
- verifying that the resulting document presents a set of requirements that are complete, consistent and measurable.

Steps five and six address development activities focusing on model conceptualization and physical realization. During each activity, the independent agent is concerned with both validation and verification. In particular, the agent:

- verifies that the conceptual model accurately reflects the requirements derived during System and Objectives Definition,
- verifies that the physical (or communicative) model(s), is an accurate reflection of the conceptual model,
- assesses the validity of the data to be used to validate the conceptual and physical model,
- monitors the validation tests performed by the developer,
- reviews the test results,
- performs additional validation tests as needed, and
- reports verification and validation exceptions to both the customer and to the developer for correction.

The transition from step six to step seven results in a programmed representation of the communicative model. Similar to the activities listed during model development, the independent agent:

- verifies that all elements described by the model are accurately reflected in the programmed representation,
- examines the validity of the data to be used for validating the programmed representation,
- monitors validation tests,
- examines validation test results for inconsistencies and discrepancies,
- when specified, examines the programmed model for adherence to
  - (a) coding standards and practices, and
  - (b) quality criteria, and
- reports all verification and validation exceptions to the customer and to the developer for correction.

Step eight comprises the simulation experiment design. More specifically, it reflects the design of one or experiments that have defined objectives, input data sets, output formats, and an evaluation procedure. The experiments are performed using the programmed model and results are examined to determine how well they correlate with real-world expectations. Primarily, the tasks of the independent agent are focused on verifying and validating the design of the experiments, their execution and result interpretation. Those tasks entail:

- verifying the accuracy of the design relative to specified design objectives,
- verifying that experiment instantiation (or implementation) correctly reflects the design,
- verifying that the parameters of the experiments fall within the boundaries that the programmed model is intended to operate,
- examining the validity of the data to be used to be used in the experiment relative to experiment objectives and expected output,
- monitoring the experiment to ensure that specified procedures are performed,
- assisting in the interpretation and validation of the results, and
- reporting validation results to the customer and developer.

At this point in time both the communicative and experimental models have been validated, i.e., the correct models have been developed. Verification has proceeded in a stepwise fashion to ensure that each intermediate artifact is built correctly. Throughout the development process, the independent agent plays an active role in:

- assessing the validity of each artifact,
- verifying that each artifact is an accurate reflection of its predecessor,
- providing constant feedback to both the customer and developer, and although not explicitly stated,
- ensuring that
  - (a) all deficiencies are corrected, and
  - (b) all changes are appropriately propagated back through previously developed artifacts.

5 SUMMARY AND CONCLUSIONS

Within the modeling and simulation community, verification and validation techniques are being applied during the development effort. Unfortunately, validation appears to play the more prominent role, with verification playing a secondary role, and only cursory attention being given to independent V&V. Independent verification and validation is not intended to replace existing V&V activities. Instead, it is intended to supplement those activities, and to provide an effective way to address the increasing complexities of modeling challenges facing the M&S community. Because of the additional costs, independent V&V is not a viable option for all development efforts. Nonetheless, we ask that the reader consider that as the size and complexity of simulation models increase, so do the benefits of independent V&V. In a brief review of those benefits, we illustrate how independent V&V can assist in building a better product and mitigate costs through early error detection.

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