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AN INTEGRATED APPROACH TO VERIFICATION, VALIDATION, AND ACCREDITION OF MODELS AND SIMULATIONS

Don Caughlin

Space and Flight Systems Laboratory
University of Colorado at Colorado Springs
Colorado Springs, CO 80933-7150, U.S.A.

ABSTRACT

In an M&S-Based Systems Acquisition, computer simulation is used throughout the development process not just as an analysis tool but also as a development tool. In general, development of a system capability using M&S-Based Systems Development will result in multiple models or simulations to meet specific needs. The Verification, Validation and Accreditation (VV&A) of each these tools is integral to M&S development. Integrating Verification and Validation (V&V) activities with M&S development and then integrating the VV&A activities for all of the M&S resources that support a program provides a cost effective approach to ensure the necessary confidence in M&S results within the time and resources available. This paper presents such an integrated approach to VV&A from a system perspective and identifies the relationships between the M&S resources in an integrated V&V program.

1 INTRODUCTION

In Modeling and Simulation (M&S)-Based Systems Acquisition, computer simulation is used throughout the development and deployment process not just as an analysis tool but as a development, integration, test, verification and sustainment resource.

Early in the engineering process, simulation is required to answer many of the performance questions relating to the capabilities of a proposed system since prototypes do not exist and it is not possible to perform live tests. As the system is developed, simulation is used to verify the performance of the design. Once prototypes are available, virtual simulations can validate that the prototypes perform as specified by the design. Finally, simulation can support testing and verification that system requirements are met.

In general, development of a large-scale system capability using M&S-Based Systems Development will result in multiple models or simulations to meet specific needs. To support total system development, some of these M&S tools will provide detailed representations of the components of the system while others will provide system level representations.

The Verification, Validation and Accreditation (VV&A) of each these tools is integral to the development and use of M&S and, therefore, to the success of the system acquisition program. VV&A consists of V&V and Accreditation. Accreditation is a statement by the M&S sponsor that the M&S is acceptable for its' intended use. This paper does not address the Accreditation part of the process.Integrating the VV&A activities for all of the M&S resources that support a program provides a cost effective approach to ensure the necessary confidence in M&S results within the time and resources available.

This paper addresses long term Verification and Validation V&V goals and presents such an integrated approach to VV&A from a system perspective and identifies the relationships between the M&S resources in an integrated V&V Program.

1.1 Problem Statement

While critical to the success of the program, VV&A is perceived as being too expensive and too late with the extent of the VV&A activities defined by available time and budget (Muessig 1997).

There are several efforts under way to address this perception (see the references and supporting bibliographies). However, most of these efforts focus on VV&A techniques and activities, the selection of specific activities to address M&S V&V questions and the definition of principles or procedures for effective VV&A.

In addition to specific VV&A processes and activities, development of a large-scale system capability using M&S-Based Systems Development requires a V&V Program structure that facilitates M&S V&V throughout the system development program.

1.2 Research Contribution

SIMVAL 99 Working Group I (Verification Technology), Issue g, "Should M&S Development Technology be better integrated with the VV&A Process," recommended that the M&S community do a better job of following the guidance provided by the DMSO Recommended Practices Guide (DoD 1996). Working Group 2 (Validation Methodology and Technology) addressed this in SIMVAL 99 Final Report Figure WG2-2, Development Cycle and V&V (SIMVAL 1999).

The Verification, Validation & Certification (VV&C) Tiger Team (DoD 1998) provided the DMSO M&S Life Cycle model (see Figure 1) as a set of IDEF0 diagrams clearly depicting the integration of the VV&A Process with the M&S Development Process and explicitly presented the data flow between the different activities. The VV&C Tiger Team also identified a lack of integration of user data V&V with the M&S V&V.

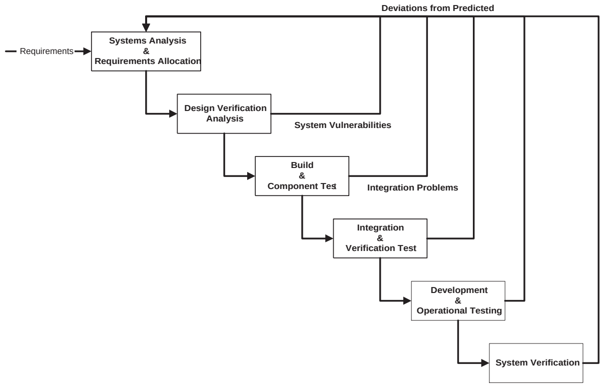

Figure 1: M&S-Based Systems Development Approach

We will see below that VV&A requires analysis of both models and data (Sargent 1999) and that it is based on Intended Use (Principles of VV&A, Balchi 1998). Therefore, in addition to the five prerequisites in Muessig (Muessig 1998), efficient, cost effective VV&A requires a clear well-defined focus/direction, and a V&V program structure that facilitates the generation, flow, and use of data in the V&V process.

This paper addresses the V&V Process and a provides a V&V Program structure to meet all of the above requirements. In Section 2, the Background presents the concept of a M&S-Based System Acquisition by addressing Simulation Based Acquisition (SBA) and the Simulate Test Evaluate Process (STEP). After presenting the program strategies, we discuss the classes of M&S tools that support these strategies, and the relationship between the system, a model of the system and its' execution in a simulation. We then continue with an introduction to the data used to support V&V. Section 3 discusses some aspects of V&V while Section 4 addresses the main result of the paper and presents an integrated V&V Program.

2 DEFINITIONS AND BACKGROUND

2.1 Definitions

System - A system is defined to be a collection of entities, people or machines, which act and interact together toward the accomplishment of some logical action. A system is also a collection of items (called components) from a certain sector of reality that is the object of study or interest. A system is characterized by the following properties (Osborne 1977):

1. It has integrity, it can be observed as an entity
2. It is measurable, that it is and has quantifiable attributes
3. It is systematic, that is fundamental relations can be observed between the quantifiable attributes

Model - a structure that can be used for understanding the behavior of a system.

Behavior - refers to the outcomes recognized by the system or model (Willems 1991). These outcomes are the trajectory of the system where "trajectory" is not restricted to time dependent behavior but includes relationships between sets of system or model attributes (e.g. phase space). From a software implementation perspective, a behavior encapsulates a set of data, a set of methods and an engine that controls the activation of the methods (Guessoum 2000).

Programs - The paper references multiple "programs." The Development Program refers to all activities related to the development of the end product, the system. The M&S Program is related to the development of a specific M&S tool within the context of the overall development program. The final program discussed is the V&V Program. The V&V Program refers to the V&V (possibly VV&A) activities associated with a specific M&S tool. The V&V Program would not refer to a V&V Strategy applicable to multiple M&S tools.

2.2 M&S Based System Acquisition

Recently, M&S-Based Systems Development is being applied to a much broader class of systems. In M&S-Based Systems Development, computer simulation is used throughout the development process not just as an analysis tool but as a development tool. In a M&S-Based Systems Development effort, the simulation must directly support (shown in Figure 1): Analysis; Design Verification; Build and Component Test; Integration and Verification Test; Development and Operational Testing; and System Verification.

With M&S-Based Systems Development, design, development, integration, and test are now continuous processes where simulation is used to validate performance, correct deficiencies, and mature the system to the point of deployment.

The principles underlying M&S Based System Acquisition are captured in two Department of Defense (DoD) initiatives: (1) Simulation Based Acquisition; and (2) the Simulation, Test and Evaluation Process.

Simulation Based Acquisition (SBA) is a concept in which M&S as a resource is more efficiently managed in the acquisition process. In the DoD environment, SBA is an integrator of simulation tools and technology across acquisition functions and program phases and across programs (SBA 2000).

The Simulation, Test and Evaluation Process (STEP) is a major DoD initiative designed to improve the acquisition process by integrating M&S tools with Test and Evaluation (T&E) activities (STEP 2000). STEP is a move beyond the "test, fix, test" approach to a "model-simulate-fix-test-iterate approach" with problems fixed as they are discovered. This approach, (model first; simulate; test; fixing after each step and then iterate the test results back into the model), is reiterated throughout system development. When a need to fix is discovered, the time for each fix can be much shorter when the fix can be verified in the model in hours or days, as opposed to a field test which can take weeks or months to verify a fix.

Caughlin (1998) analyzed M&S-Based Systems Development simulation requirements by evaluating the development activities to determine different uses of simulation. In analyzing these activities, there were similarities that suggested two different classes of simulation - Analytical and Interactive. In each of these classes specific uses were identified. See (Caughlin,1998) for a discussion of M&S requirements to support M&S-Based Systems Development.

2.3 M&S Classes

Integration of M&S V&V Programs will generally result in the exchange of data between different classes of simulations. All classes of M&S considered here involve computer programs that either replicate systems (existing or in some stage of development) or support actual use or testing of systems. Some M&S involve hardware, actual equipment, or personnel. Specific classes include the following (DoD 1996):

1. Constructive-computer simulations, including man-in-the-loop and hardware-in-the-loop M&S
2. Virtual-system simulators
3. Live-instrumented tests and exercises.

2.3.1 Constructive Simulations

Constructive simulations are digital simulations that range from simulations of portions of a system, process, function, or activity to complete End-to-End Digital simulations. An end-to-end digital simulation is an integrated suite of constructive component models linked together to represent the fully functioning system that is being developed. End-to-end refers to the simulation's ability to represent the system's full range of performance. For example, an end-to-end digital simulation of a homing missile system would represent the system from target detection to intercept.

2.3.2 Virtual Simulations

A Virtual Simulation is a continuum of prototypes that represents the system at various levels of fidelity. The prototypes, which operate in a synthetic environment, can be entirely software, or a combination of hardware and software.

2.3.3 Live Simulations

A live simulation is a test, in a controlled environment, of the complete system, components of the system, or prototypes for the purpose of supporting its' development or acquisition.

2.3.4 M&S Class Summary

In summary, there is a continuum of M&S tools from fully digital to test that can be used to support the development and acquisition of a system. Each of these classes has different capabilities and regions of validity. Figure 2 shows how these simulation classes can be used in the acquisition of the system.

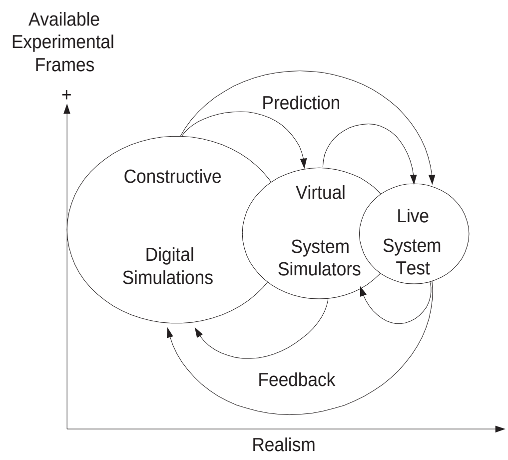

Figure 2: Connection of Simulation Classes to Support System Acquisition

The Experimental Frame specifies the conditions under which the system is observed. (Zeigler 2000). Figure 2 also shows how the realism increases as we move from simulation to test while the conditions under which we may observe the system decrease.

2.4 Systems, Models, Simulations and Prototypes

For this paper we define a system as a set of coupled (integrated) components.

A model is an abstraction of a “real world” concept or system where we have analyzed the “real world” system, determined the behaviors that will be addressed by the model and determined a structure for its representation (Caughlin 1997).

A prototype is an initial model of a system or component. As a model, it is not expected to replicate nor have the same capabilities of the production system. A prototype should however, have the same structural characteristics so that it is representative of production system use and performance.

2.4.1 Levels of Simulations

Given that a system consists of coupled components, there are two levels of models, simulations and/or prototypes that can be developed.

In the first instance, models, simulations and/or prototypes of individual components can be developed. Simulations of the individual components are referred to as component level simulations.

Secondly, we can develop a model or simulation of the entire system. There are two approaches:

1. First, component models, simulations, and/or prototypes can be connected/coupled (e.g. using the High Level Architecture) to represent the system.
2. Secondly, a simulation of the system can be developed without using the component models, simulations, and/or prototypes discussed under the first option (digital end-to-end simulations).

Coupled component level simulations that represent the system or digital end-to-end simulations of the system are referred to as system level simulations.

2.5 Data

There are three kinds of data in a system development program. The first kind of data are Program Data and is associated with development, manufacturing, deployment, and sustainment of the system. The second type of data are Design Data associated with documentation/definition of system requirements, capabilities, architecture, interfaces and performance. The final data are T&E data associated with test results.

2.5.1 Data Generation and Flow

Program, Design and Test Data influence the development of M&S tools. In addition, we will see from the V&V Paradigm below that V&V must address both the M&S as well as the data associated with the M&S. Therefore, a discussion of V&V must address the generation and the flow of data throughout the system development process.

The design processes (System Engineering, Software Engineering, the Specialty Engineering disciplines, and Product Assurance) begins with customer requirements and synthesizes a system to meet requirements (EIA 1994). Consequently, the design processes generate Design Data that are captured in the Design Database.

Dependent on but separate from the design processes, the T&E process evaluates aspects of the performance of the system produced from information in the Design Database. This data are collected in the Test Database.

Program, Design and Test data are generated by many different organizations within the development program. Both system and component product teams produce data (e.g. Product Assurance within a product Team or the T&E team both produce Test Data). From the above, we also see that data are generated at both system and component levels.

2.5.2 M&S - Data Interface

Development of M&S resources is driven by program requirements from Program, Design and Test data.

Program Data define the Intended Uses of the M&S, its development schedule and the actual capability required by the M&S representation.

Design Data both drives and is driven by the M&S. The Design Database establishes the domain of the model or simulation by acting as the definition of the real world that the model or simulation is supposed to represent. In addition to defining the M&S representation, the Design Data can be generated, modified, or validated by M&S tools.

Test Data can be used as part of the modeling process (possibly populating a lookup table) or to validate results of the model.

Because of the flow of information from the databases to the M&S, the models, simulations, prototypes, and test (of the actual system) generate data for all development functions (Program, Design, and T&E).

3 VERIFICATION AND VALIDATION

3.1 Overview

Verification and Validation are often considered as a single process, yet there is a distinct focus to each and a distinct capability provided by each. Verification focuses on M&S capability, whereas validation focuses on M&S credibility.

Verification is “the process of determining that a model implementation accurately represents the developer’s conceptual description and specifications." Validation is"the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the *intended uses of the model*."

For systems that exist, validation can use "real world" system data to demonstrate the adequacy of the simulation. Simulations of proposed systems do not have the "real world" data to use for comparison. Simulations of proposed systems must rely on prototype (test) data, analogous system data, or analysis data as a source for validation.

Verification without validation increases the confidence in the simulation but always leaves a measure of doubt as to its representation of the real system. Validation without verification limits the use of the simulation to the understanding and analysis of a point design. The combination of Verification and Validation allows the use of the validated simulation to investigate new operating conditions or system modifications to improve some element of the performance.

3.2 V&V Paradigm

One M&S verification and validation approach has evolved from a model developed by Dr. Sargent of Syracuse University (Figure 3). This diagram shows how V&V activities interface with the simulation development process.

The inner triangle in Figure 3 illustrates the process of model development - evolving from "problem" to simulator. The outer circle, along with data validity (in the center) and internal security verification (lower left) represent the testing processes necessary to prove that the model is credible. The V&V process examines both the inner triangle to determine if model development was sound, and the outer circle to determine if the model has fully demonstrated the capability required to meet the intended use.

The final step is comparing the model outputs to the real world or engineering judgement. The confidence in a model or simulation is a function of the time and effort applied to the evaluation or assessment. M&S V&V should apply an incremental, customized approach to each model/simulation verification and validation to accommodate varied constraints of time, schedule, previous use, and resources.

3.3 V&V Processes

One assumption in the discussion of integrated V&V is that the M&S V&V Process can be mapped into the generic DMSO V&V steps shown in Figure 4 (DoD 1996).

From the chart we see that the primary steps in VV&A are:

1. Requirements Validation
2. Conceptual Model Validation
3. Design Verification

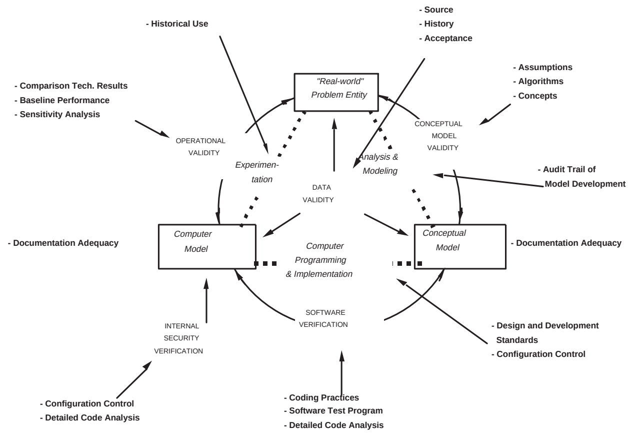

Figure 3: V&V Evaluation Structure

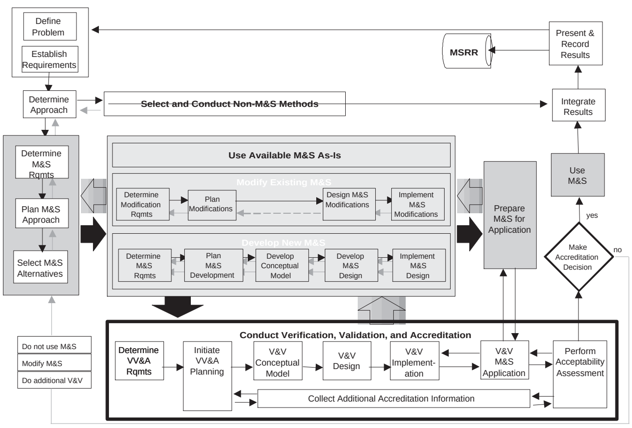

Figure 4: DMSO Generic VV&A Process

4. Implementation Verification
5. Results Validation

The Results Validation process is critical to the integration of V&V Programs and is discussed further.

3.3.1 Results Validation

Numerical predictions obtained from selected test points within a simulation/model to be validated can be compared to equivalent test data types in order to validate the model. This is called Results Validation. Results Validation using real world (prototype) data increases the confidence in the M&S resources and also provides higher fidelity answers to specific questions.

Results Validation is is defined as the comparison of M&S predictions with experimental (test) observations (measurements) for the purpose of ensuring the fidelity (as defined below) of the M&S representations of the system/subsystem. The term "fidelity" is used as a measure of M&S performance. To define the fidelity of a model or simulation, we include the number of allowable behaviors addressed, the resolution of the description of the behavior and the accuracy of the result.

The Results Validation procedure is based on the identification and analysis of comparable data (Balchi 1998b). Identification of the comparable data is defined by the intended use of the M&S and the behaviors recorded in the data and allowed by the M&S. Comparison of the data must be consistent with the method of abstracting the behaviors along with data resolution and accuracy.

In general, the method of abstracting a behavior in the M&S will differ from the process that generated the data set that is to be used for Results Validation. For example, output data generated as the result of a test configuration may be represented in an M&S as an input parameter or a transient object passed between two components. Consequently, in identification of comparable data items, we must address the different uses of the information (data) within the simulation and test environment as further discussed below.

The Results Validation process is shown in Figure 5. This process compares the respective outputs in detail, and analyzes the causes for differences in outputs. The comparison can be accomplished statistically, by technical judgement, or by a combination of both. The statistical approach must be assessed carefully by the engineering or technical experts in order to avoid erroneous blind conclusions. Technical judgement on the other hand is not as formally rigorous but introduces extensive engineering, scientific or mathematical judgement to assess the reasonableness of both the test data and simulation/model output. See (Caughlin 1999) for a detailed discussion of the process.

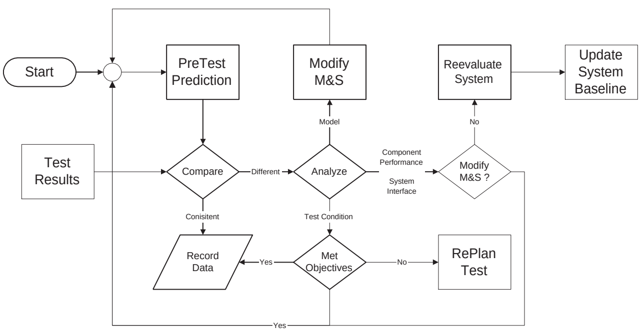

Figure 5: The Results Validation Process

3.3.2 Results Validation Using Test Data

In the execution of Results Validation we must consider the relationship between the test and M&S environments.

While test is probably the highest fidelity representation of the prototype system, limitations in the test program usually will not allow exercise of the system in its true production configuration or through out its complete envelope (recall Figure 2). The portion of production environment exercised by the test is depicted in the circles in the Venn diagram in Figure 6 (proportions are for illustration only - no scale is intended).

From Figure 6 we see that some functionality (data) of the test are representative of the production system while others are not. Now consider a simulation of both the test (by a HWIL simulator) and of the production system as shown in the rectangles of Figure 6. Simulation of each environment/configuration of is not an exact representation. The differences between the test and HWIL simulation as well as the difference between the production system and the system simulation must be accounted for.

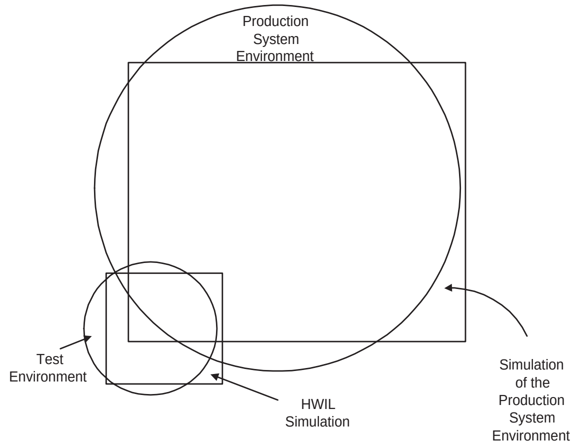

Figure 6: Simulation of the Test and Production Systems

Two points are worth noting from the above figures. First, while the test may be a higher fidelity representation of the prototype, only some of the functionality applies to the production system. Secondly, the simulation of the system/test is not exact. It does not cover all of the behaviors also may provide outputs that would not be allowed by the actual configurations. Therefore, care must be taken in the selection of the data that will be used for Results Validation.

The Results Validation Process must define the "accuracy" of the data and determine which data can be used for the purpose of ensuring the fidelity of the M&S. In general, the following assumptions are made for the Results Validation process:

1. The tests are simulations of the prototype (as is) system.
2. The test is the most accurate representation of the prototype system.
3. Once validated by test, the HWIL simulation is the next most accurate simulation of the prototype system.
4. Once validated, the digital simulation follows the HWIL simulator as a depiction of the prototype system.

5. Once validated, the digital simulation is the best representation of the production system in its' intended environment.

3.4 Analysis

As seen in Section 2.4.1, a M&S-Based Systems Development program would normally require M&S activities that function at two separate levels - the component level and the system level. At the component level, it would be expected that there would be at least one simulation of each component. At the either the system level or within a component, there can be multiple simulations of the same system/component depending on the intended use.

In Section 2.5.2, we saw that there is a two-way connection between the Design Database and M&S tools. Design Data is used in the construction of the simulation primarily in the development of Simulation Requirements and the Conceptual Model. Program Data provides the intended use. Once developed, the M&S tool can be used to add to, modify, or validate Design Data. The fact that the same data source used to develop the M&S tool can be modified by that tool can lead to a situation where the system Design Data and M&S tool diverge from the actual capability of the production system. This is another reason why Results Validation is so important.

Therefore data are used by and generated by M&S tools at both system and component levels (possibly by multiple models or simulations at each level) by different organizations and by different development teams (e.g. SE and T&E). All of this data adds to, modifies, or validates the Design database.

4 V&V Integration

In summary:

1. Program data flow to and from the Program, Design and Test Databases, between multiple organizations supporting different activities (e.g. SE and T&E), and between different levels (system and component) within the program. These same data flow between product and M&S development functions.
2. The DMSO M&S Lifecycle integrates the M&S Development and V&V Programs.

Combining these two observations with recommendations from SIMVAL 99 and the VV&C Tiger Team, we propose the integration of the V&V program into other development program activities. This integration can provide a clear well-defined focus/direction and a program structure that facilitates the generation, flow, and use of data in the V&V process for cost effective VV&A.

Taking a data flow perspective, four types of V&V integration are required. First the M&S V&V Program should be integrated with the M&S development. Secondly, the system and component level V&V Programs should be connected. Next, the V&V Program for a M&S tool that supports a particular development function (SE, T&E, etc.) should be integrated with the other development program functions (as applicable) to support efficient data flow. Lastly, the V&V programs of the different M&S activities should be integrated. Special consideration should be give to the V&V Programs supporting M&S tools at different levels (system and component).

4.1 Integration of the M&S Development and V&V Programs

The fact that M&S Development and V&V should be integrated is well known. The contribution here is the definition of the V&V Program activities (e.g. validation of requirements as opposed to V&V of requirements) and the direct connection to the Software (SW) development process.

The focus of the V&V is provided by the Acceptability Criteria. This is the M&S Sponsors' reason for developing/modifying and using the simulation and provides the V&V requirements and the Intended Use, which form the basis of the assessment activities. The direction of the V&V program is provided by model development activities. The direction and focus should be consistent because these activities are driven by the same requirements that generate the Acceptability Criteria.

Implementation of the focus and direction is best accomplished by explicitly integrating the V&V Activities into the M&S development program shown in Figure 7. This puts the V&V activities directly into the M&S Development process and provides additional direct and immediate feedback to the model developers. This feedback is generated without additional (out of cycle) meetings, deliveries, or reviews.

By virtue of the fact that the development of M&S is integrated with program objectives, integration of M&S Development and V&V provides the connection between M&S V&V and the Design Database and the system development.

Much of the V&V Process, then, becomes an audit of the execution of the SW Engineering activities and methods and an analysis of the artifacts produced during the M&S Development Process.

4.2 Integration of System Level and Component Level M&S V&V Programs

The next integration is the coupling of the component and system level M&S V&V activities. This coupling takes two forms, one direct and one indirect. The indirect integration is the communication that takes place between system and

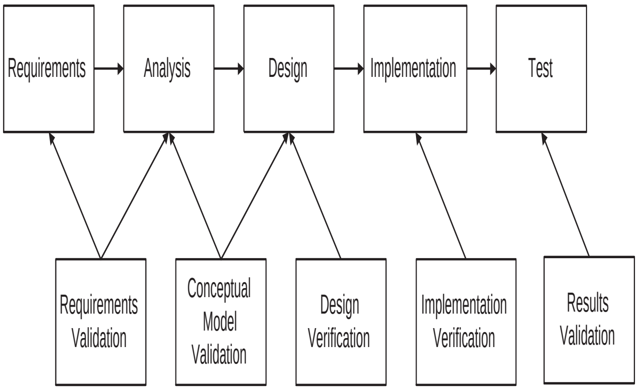

Figure 7: Development and V&V Program Interaction

component levels through the Design Database. The second form of integration is a direct connection using the Results Validation relationships shown in Figure 8.

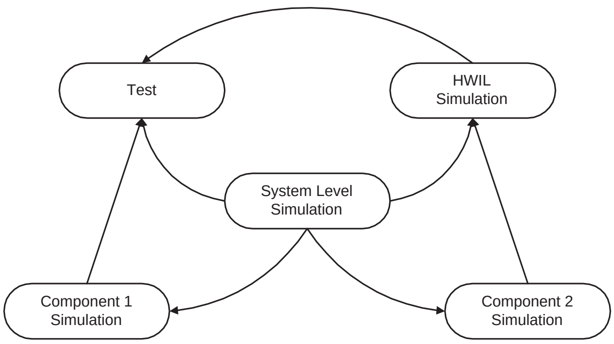

Figure 8: Results Validation Relationships

First we discuss the indirect process. Systems Engineering is a top down hierarchical approach consisting of an iteration between the project domain and an abstraction domain (Brown 1993). The abstraction domain is a functionally oriented domain where each function serves a purpose in the project domain. Requirements are allocated among system functions and when functional components are coupled together, interfaces are defined between them.

The system level Systems Engineering process uses M&S tools specifically defined to address system issues. The implication here is that the model abstraction process used to support the M&S tools addresses aggregate behaviors applicable to the system as a whole. This aggregation will make assumptions (based on the requirements) relating to component level performance.

As the system begins to take shape, system functions and their requirements are allocated to physical components. At this point a component level product (engineering) team is established and component level System Engineering begins.

Component level System Engineering refines component designs and performance estimates. The focus is on a design that meets component requirements as allocated by system level System Engineering. These estimates are typically derived from detailed component level simulations.

This is where the integration of the M&S programs should take place. As component engineering progresses, specific component design details and algorithms are provided as updates to detailed component level simulations to ensure they represent the current component design.

As the component level simulations are refined, performance details and data from the component level representations are provided to the system level simulation to refine component performance within the system level simulation. This new information is integrated into the system level simulation.

Since integrated components make up a system. Execution of the component level simulations requires input from other components within the system. These inputs are not available from within the component level simulation but must be provided as exogenous inputs. To the extent possible, these inputs should be derived from system level simulation. Driving each of the component level simulations with inputs derived from system level simulation helps couple component System Engineering activity to the system level. In addition, using inputs derived from the system level simulation continues the interface definition process by addressing the functional as well as physical connection between system components. This integration is shown in Figure 9 and is supported by the Results Validation process.

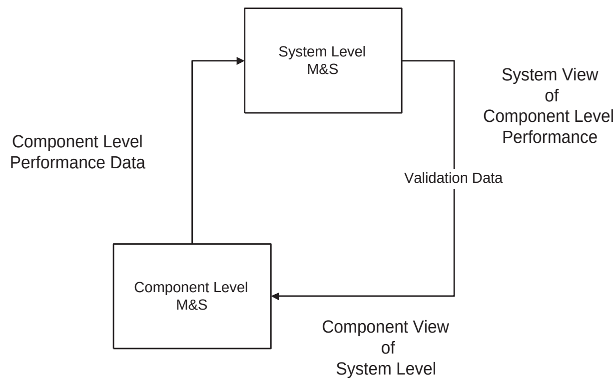

Figure 9: Integration of System and Component V&V Programs

Now we discuss the second form of integration - a direct connection between the component and system level M&S V&V activities using the Results Validation relationships shown in Figure 8.

M&S development teams at both the system and at the component level are responsible for insuring that adequate V&V activities are performed to allow confident use of the M&S tools. Independent execution of this process by the system and component level M&S teams, however, fails to capitalize on the potential synergy of the two sets of activities.

Historically, Results Validation has implied the comparison of M&S results to real world data from prototypes, tests, etc. Integration of system and component level V&V extends this historical use.

Following each update cycle, the simulation teams (system and component) should compare the performance of the component simulation with the representation of component performance within the system model. By explicitly integrating this comparison as part of Results Validation of each M&S tool, the additional data can be used to increase the confidence in both sets of simulations.

4.3 Integration of M&S V&V with Other Functions (SE, T&E)

While the integration discussed above will connect the V&V program to the function is it directly supporting (System Engineering, Integration, Test and Evaluation, Deployment, Sustainment, etc.) it does not necessarily connect the V&V Program to the other functions or organizations that generate data. For example, if a SE simulation is not beng used by T&E, then integration of M&S Development and V&V would not connect the M&S V&V Program to the T&E activity. Yet there may be data available from T&E that could assist the M&S V&V.

A connection between M&S V&V and other system development functions can be made during Results Validation and is applicable to both system and component level M&S.

Recall that Results Validation compares M&S Predictions to data. The primary data sequence is as follows:

Test => HWIL Simulation => M&S

This means that HWIL simulators will be validated by test data and both test and HWIL simulator data will be used to validate other M&S tools.

With the integration of system and component level V&V, there are now two data sequences are used for Results Validation. Within the levels of simulations, the Results Validation sequence proceeds from the component to the system with system level component representations validated by component data:

Component M&S => System M&S

The data sources and M&S resources that will be compared to data are shown in Figure 8. These relationships integrate SE, Integration and T&E.

4.4 Integration of M&S V&V Programs

Integrating V&V programs of the different M&S activities is straightforward if the M&S Development Programs are integrated. For example, if data from one M&S tool is used in another tool, one of the Intended Uses of the first tool would be generation of data for the second. V&V of the M&S for that purpose flows directly into the second V&V program.

If the M&S Development programs are not integrated, there should be no expectation that the V&V Programs of the different tools would be connected. However, the capture and use of the data from the different M&S programs still can be accomplished in the M&S V&V Results Validation step.

5 CONCLUSIONS

The proposed integration facilitates the data flow among all of the organizations within a program. The connections are straightforward, simple, and can be applied to any system development. The proposal addresses concerns addressed relative to the use of data and the integration of the M&S development and V&V.

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AUTHOR BIOGRAPHY

DON CAUGHLIN is Acting Director of the Space and Flight Systems Laboratory at The University of Colorado at Colorado Springs and President of Dynamic Computing Services, Inc. He received a BS in Physics from the Air Force Academy, an MBA from the University of Utah and MS and Ph.D. degrees in Electrical Engineering from the University of Florida. His research interests include modeling and simulation, system id and intelligent control. Dr. Caughlin has over 32 years experience as an experimental test pilot, chief scientist, researcher, program manager and was also Associate Dean of the School of Engineering at the Air Force Institute of Technology. He is a senior member of IEEE and AIAA and a member of SCS and the Society of Experimental Test Pilots. His email address is <dcs@rmi.net>.