

Validation

RPG Special Topic

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Table of Contents

Validation Fundamentals	1
Referent Selection	4
General Referent Issues	5
Subject Matter Experts (SMEs)	8
Validation Data	10
Preparing Comparison Inputs	13
Requirements Articulation	14
M&S Characterization	16
Comparison Techniques	19
General Comparison Issues	20
Comparison Technique Selection	24
Evaluating Comparison Results	27
Validation Planning and Management	29
Management Issues	29
Validation Planning Issues	34
Scenario Concerns	39
Special Validation Problems	41
References	42
External Links in This Document	43
RPG References in This Document	43

Validation Fundamentals

The issues addressed in this section are

- [What is validation](#)
- [Why is validation important](#)
- [What is the relationship between validity and credibility](#)
- [What is the relationship between validation and verification](#)
- [Where in the V&V process should validation be performed](#)
- [What special challenges does validation present](#)
- [What are the essential steps in validation?](#)

What is validation?

The current version of the *DoD Modeling and Simulation (M&S) Glossary* [DMSO, 1997] defines validation in the following way:

validation. The process of determining the degree to which a model or simulation is a faithful representation of the real world from the perspective of the intended uses of that model or simulation.

In this definition, the term “real world” refers to the physical world both that currently exists and that may exist in the future (e.g., a future system development; an anticipated threat environment). Section 1 of *A Practitioner’s Perspective on Simulation Validation* [RPG reference document] provides further perspectives on the meaning of validation for various purposes.

Why is validation important?

The validation process establishes the faithfulness of the model or simulation to the thing being represented, the **simuland**. Validation provides a crucial piece of evidence to support model or simulation credibility for a particular application. The validity of a model or simulation also helps reduce the risk. This is especially critical in a project that employs simulations to guide its development and management decisions [Harmon et al., 1999]. Section 1 of *A Practitioner’s Perspective on Simulation Validation* [RPG reference document] adds further insight into the link between model or simulation validity and credibility.

What is the relationship between validity and credibility?

The validity of a model or simulation supports but cannot guarantee its credibility in all cases. Credibility relies upon the trust that a User has in

- the validation results
- the process that produced those results
- the people that executed that process¹

Users must believe in the credibility of a model or simulation before they will use it or its results. Often, the accreditation of a model or simulation makes a substantial contribution to this belief.

What is the relationship between validation and verification?

Verification determines that the design and implementation of a model or simulation correctly meet the design requirements as best reflected in a validated **conceptual model**. Thus, when properly executed, a verification process ensures that the design and implementation processes have preserved the validity of the conceptual model in the working simulation. Further, verification supplements any validation effort with such important documentation as requirements traces and verification records that validation alone may not provide².

Where in the V&V process should validation be performed?

The V&V processes for any type of model or simulation recommended in this guide, depicted in the diagrams for VV&A and New M&S Development, VV&A for Legacy Preparation, and VV&A and Federation Construction, include

- conceptual model validation
- results validation

The results validation activity includes a number of validation tasks such as

- validation of required human behavior representations and their associated knowledge bases³
- validation of simulation algorithms and models and their associated data⁴

¹ see the special topic on Fidelity

² see the core documents on the V&V Agent Role in the VV&A of New Simulations, Legacy Simulations, and Federations and the reference document on V&V Techniques for more information on verification and the techniques that support it

³ see the reference document on Human Behavior Representation Validation

⁴ see the special topic on Data V&V for New Simulations

What special challenges does validation present?

Validating models and simulations involves several special challenges as shown in the table.

Special Challenges in M&S Validation
• Getting enough time and commitment from the Users of a model or simulation to sufficiently and accurately describe their validation requirements, often stated informally, incompletely and inconsistently
• Reconciling different ideas about the representational requirements for the model or simulation into a single complete and consistent set of requirements
• Obtaining sufficient and accurate information describing the functionality and performance of the system being modeled, especially if that system exists only conceptually
• Validating a conceptual model described entirely informally and perhaps incompletely, thus leaving considerable room for qualitative interpretation about the degree to which the model faithfully represents the world being simulated
• Balancing project schedule and cost constraints against validation needs that may result in a model or simulation with less validity than desired
• Justifying the investment required to support the extent of the validation process necessary to assure sufficient model or simulation credibility for a User

Other sections in this document address these challenges from various perspectives.

What are the essential steps in validation?

The figure below illustrates the essential steps for performing validation at any stage in the V&V process, including validating the conceptual model, the knowledge bases, or the results of a model or simulation.

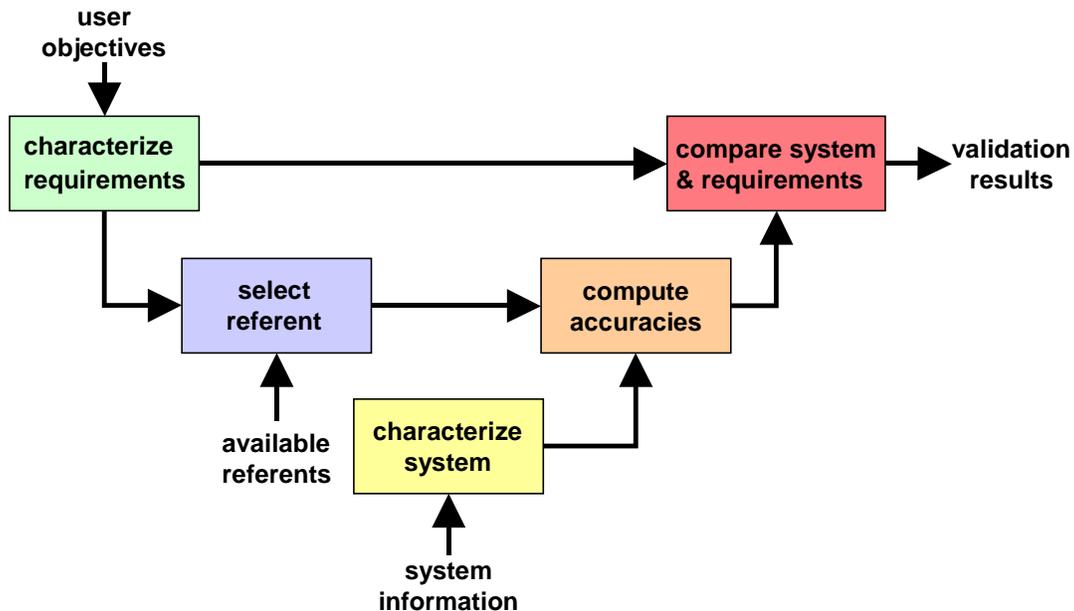
Validation of a model or simulation starts with a

- complete and consistent statement of the requirements derived from the User's objectives (see the reference document on [SIW Fidelity Report](#))
- description of the characteristics of the model or simulation
- description of the referent against which the model or simulation will be compared for fidelity

Then the model or simulation characteristics are compared with those of the referent relevant to the User's purpose. The results of this comparison, defining the model's or simulation's fidelity⁵, are then compared with the requirements. If the representational capabilities of the model or simulation fall within the tolerances defined by the

⁵ see the special topic on Fidelity

requirements, then it has sufficient validity to meet the User's purposes. Section 1 of A Practitioner's Perspective on Simulation Validation describes a seven-step process that captures these essential aspects of validation and the reference document on Statistical Concepts and Methods for Model Validation describes a rigorous mathematical approach to comparing models with referents and model capabilities with requirements.



Essential Steps for Validating Models and Simulations

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Referent Selection

Issues addressed in this section fall in three basic categories:

- **General Referent Issues**
 - [What is a referent and how does it differ from the real system](#)
 - [How do referents contribute to validation](#)
 - [What different types of referents exist](#)
 - [How can one identify appropriate referents for a particular purpose](#)
 - [How should referents be prepared for use in validation](#)
 - [How should the referent for a nonexistent system be obtained](#)
- **Subject Matter Experts**
 - [What roles can SMEs play in validation](#)

- [How should SMEs be interviewed for the validation process](#)
- [How does one deal with disagreement among SMEs](#)
- **[Validation Data](#)**
 - [What is validation data](#)
 - [How should experimental data for validation be collected](#)
 - [How does one handle validation with limited experimental data](#)
 - [What is the cost-benefit evaluation of data collection](#)
 - [How should validation and T&E activities interact](#)

General Referent Issues

What is a referent and how does it differ from the real system?

Harmon [1998] gives the following definitions for the term referent:

referent. 1. A codified body of knowledge about a thing being simulated.
2. Something referenced or singled out for attention, a designated object, real or imaginary, or any class of such objects. [RPG Glossary]

In essence, a referent defines the best knowledge about the things that a model or simulation represents, the simulands. Referents are not the simulands themselves but rather the best information we have about their functionality and performance. The notion of referent captures the limits of knowledge about the simulands.

How do referents contribute to validation?

Referents provide the standards against which to compare the representations of models and simulations to assess their fidelity capabilities. Comparing model or simulation fidelity capabilities with a User's fidelity requirements determines the validity of that model or simulation for the User's purposes [[SIW Fidelity Report](#)]. Thus, referents are key to assessing model validity. Further, the completeness and accuracy of the referent with respect to the simuland limits the accuracy of any validity assessments that use that referent.

What different types of referents exist?

Referents exist in many forms, ranging from subjective and qualitative descriptions to objective and quantitative descriptions:

- experimental data describing the functionality and performance of a system or phenomenon under well-known conditions

- empirical data describing the behavior of a system or phenomenon under conditions ranging from unknown to well characterized
- experience, knowledge, and intuition of subject matter experts (SMEs)
- mathematical models of the behavior of a system or phenomenon that have been validated by experimental or empirical data
- qualitative descriptions of the behavior of a system or phenomenon whose validation ranges from none to extensive
- other simulations that have established credibility with the intended Users and for their particular purposes
- combinations of the types described above

How can one identify appropriate referents for a particular purpose?

The following suggestions can guide the selection of the referents needed for validating a model or simulation:

- Choose referents that represent the systems and phenomena needed to meet the User's requirements for the model or simulation.
- Choose referents that match the level of detail required for the model or simulation to meet the User's objectives.

Example:

Detailed models of quantum mechanics may not be useful for validating models of missile flyout but may be crucial for validating models of nuclear weapon behavior.

- Choose referents that are available within the cost and schedule constraints of the project. In some cases, these constraints permit creation of new referents, for example, through conduct of experiments.
- Choose referents whose information matches the characterization of model or simulation capabilities.

Example:

Representations of human behavior typically lend themselves to the qualitative comparisons available from SMEs. This simplifies the comparison process and reduces the probability of errors occurring.

- Choose referents that are consistent with the other referents being used for validation where they overlap or interact. Inconsistency between referents will create inconsistent, and possibly incorrect, validity assessments.
- Choose referents from sources that the Users trust. Referents from untrustworthy sources diminish validation credibility, and therefore simulation credibility in the Users' eyes.

How should referents be prepared for use in validation?

Referents are as varied as models or simulations themselves. However, a few general guidelines, shown in the table below, can help prepare referent information for use in validation.

General Guidelines for Preparing Referent Information
<ul style="list-style-type: none">• Choose those parts of the referent information to be compared with the capabilities of the model or simulation being validated, and document that selection process to capture any assumptions made that may impact validation credibility.
<ul style="list-style-type: none">• Transform the referent information into the units of measurement consistent with the units used to describe the simulation's representational capabilities and the User's representational requirements.
<ul style="list-style-type: none">• Test the consistency of referent information about the same objects or phenomena, especially if modeling the same objects at multiple levels of detail, and document any inconsistencies found.
<ul style="list-style-type: none">• Attempt to resolve inconsistencies in the referent data, especially where the inconsistent data are compared with the model or simulation.

Since referent information represents the best knowledge about some phenomenon it may contain more information than actually needed for validation. Complex referents only complicate the validation process. Also, referent information may be internally inconsistent, particularly where it represents observations or explanations at different levels of detail. These inconsistencies should be resolved to ensure the accuracy of the comparison with the capabilities of a model or simulation. Some inconsistencies can be tolerated if the interactions across multiple scales have negligible effects upon the phenomena being modeled. However, if the magnitude of these relationships is not well understood, then it is better to resolve referent inconsistencies.

How should the referent for a nonexistent system be obtained?

The situation of unavailable referents occurs when validating a model or simulation of a system that does not yet actually exist (e.g., a new bomber or innovative force structure). In this situation, there may seem to be no referents against which to determine the fidelity of the models or simulations of that system. However, referents are the "best" knowledge about the simuland. If enough knowledge exists to design and implement a new system or to develop a new process, tactic, doctrine or procedure then enough knowledge exists from which to create a referent. The following options exist in this situation:

- assemble a referent from knowledge about the components of the system or procedure
- assemble a referent from the knowledge about the basic phenomena underlying the system's behavior

- build a scale model of the system or its components and, using similitude, perform experiments to collect data from which to abstract a referent
- use the referents for a similar existing system or similar situations
- use some combination of the above options

In some of these cases, an initial preliminary referent can be established (e.g., using the referent from a similar system) and then refined as more knowledge is gained during development of the actual system or procedure.

Subject Matter Experts (SMEs)

What roles can SMEs play in validation?

In validation, subject matter experts (SMEs)⁶ represent referents through their experience and knowledge. Unlike most referent sources, SMEs, if selected carefully, can serve many purposes simultaneously, such as

- representing referent knowledge
- comparing model or simulation functionality and performance against their internal referent knowledge to assess fidelity
- comparing model or simulation functionality and performance against User requirements to assess validity

As a result of these multiple talents, SMEs can perform functions that support every phase of the validation process, as shown in the table.

Typical SME Tasks
• Characterize User requirements from their objectives
• Validate conceptual models
• Validate system data and knowledge bases
• Support the design of simulation test plans
• Define and develop data for use in validation and testing (i.e., validation data)
• Design test scenarios
• Perform simulation testing and validate it from the results

How should SMEs be interviewed for the validation process?

In cases of limited SME availability, it may be necessary to conduct directed interviews to extract information from which to build a referent or to formulate a conceptual model.

⁶ see the special topic on SMEs and VV&A

Section 4.2 of A Practitioner's Perspective on Simulation Validation [reference document] provides important guidance for the interviewing process summarized in the following table.

Interviewing Process for SMEs
<ul style="list-style-type: none">• Interview multiple SMEs, especially for information particularly critical to the model or simulation.
<ul style="list-style-type: none">– Be aware that some of the information SMEs provide may come from their opinions and may be incorrect for the particular situation.– Be aware that SMEs may not provide information at the correct level of abstraction for the model or simulation, giving either too much or too little detail.– Ask many questions related to the same aspect of the simuland in order to extract all of the nuances of the SME's expert knowledge.– Pose questions that create an operational context for the SMEs to efficiently tap their experiential knowledge.
<ul style="list-style-type: none">• Examine the answers to multiple questions about the same aspects carefully to detect apparent conflicts and from those formulate additional questions to resolve those conflicts.
<ul style="list-style-type: none">• Test the information obtained from SME interviews against other sources where possible to detect apparent conflicts and from those formulate additional questions to resolve those conflicts.
<ul style="list-style-type: none">• Iterate the process several times in different interview sessions to revisit areas of conflict and verify consistency for important issues.

Additional information about using SMEs effectively can be found in several places in this document and in the special topics on Subject Matter Experts and VV&A and Conceptual Model Development and Validation, and the reference document on HBR Validation.

How does one deal with disagreement among SMEs?

Apparent conflicts or disagreement in the information that SMEs provide may signal

- incorrect SME information
- individual variations in the application of the same general guidance from doctrine
- areas of poor referent knowledge from SMEs

One of the most effective ways to deal with disagreements among SMEs is to perform a structured walkthrough of the written conceptual model before an audience of all major participants (e.g., User, M&S Program Manager (PM), Developer, V&V Agent, Accreditation Agent, SMEs, analysts). Each item in the conceptual model should be discussed in detail. This is a very effective vehicle for the disagreeing SMEs and other people to discuss how a particular subsystem actually works and at what level of detail it should be modeled. This meeting also helps to ensure that the model assumptions

are correct and complete. Section 4.6 of A Practitioner's Perspective on Simulation Validation contains additional information about conducting structured walkthroughs.

In situations where structured walkthroughs may be infeasible, several other options exist for handling SME disagreements:

- ask the SMEs to resolve the conflicts themselves by interacting where possible.
- compare the SME information against another independent referent source, if available.
- ask a third SME to resolve the conflict.

(In some cases, the information from a third SME may only complicate the conflict. If this occurs than another referent source should be consulted.)

- ignore the conflict if it occurs where the objectives are insensitive to the model or simulation accuracy.

Validation Data

What are validation data?

Validation data are the actual measurements from the real world or "best guess" information provided by SMEs that are used in validation to determine if the results of the simulation are "correct enough" for the simulation to be useful in the intended purpose. Validation data⁷ are the real world facts used for comparison to validate the results of a simulation. They come from empirical sources such as test ranges; live exercise results; historical records; outputs of other, previously validated simulations; experiments; or, from the knowledge of SMEs. Additional information about validation data is available in the special topic on Data V&V for New Simulations.

How should experimental data for validation be collected?

Experiments can be expensive to conduct and repeat so they should be carefully selected and designed. Several standard texts exist to guide experiment design, and they should be followed judiciously to maximize the correctness of the data collected. The following table provides some general guidance for collecting experimental data specific to the validation of models and simulations:

⁷ see the reference document on M&S Data Concepts and Terms

General Guidance for Collecting Experimental Data
<ul style="list-style-type: none">• Avoid experiments by using data from previous experiments where possible and appropriate. However, carefully examine the conditions under which the data were collected and analyzed to ensure their appropriateness for the situation being represented.
<ul style="list-style-type: none">• Identify the most important aspects of the model or simulation to validate by performing sensitivity analysis [Harmon et al., 1999] or risk analysis⁸ and collect experimental data related to those aspects.
<ul style="list-style-type: none">• Identify the conditions to which the model or simulation is most sensitive and the ranges of most concern, and use those to focus the experiments.
<ul style="list-style-type: none">• Design experiments that explore the conditions that most closely match the actual use of the system. If this is not possible, identify or derive relationships that permit the interpretation of experimental data in a context closely relevant to the actual use conditions.
<ul style="list-style-type: none">• Attempt to vary only one condition with each experiment while controlling the others as much as possible. Poorly designed and conducted experiments can only yield equally poor referents, and these can contaminate the entire validation process.
<ul style="list-style-type: none">• Carefully vary conditions to uncover ranges over which experimental variables are sensitive. These ranges may identify areas where additional experimental data or information from other referents is necessary.
<ul style="list-style-type: none">• Repeat experiments under identical conditions to characterize stochastic influences. A single experimental result describing random processes is useless.
<ul style="list-style-type: none">• Test experimental data and the results of data analysis by comparing them with accepted theory and data from other independent experiments. These tests can reveal previously unknown error sources.
<ul style="list-style-type: none">• Understand the sources of experimental errors, their nature and magnitude. This may require performing additional experiments just to characterize error sources. Additional error source information comes from other experiments dealing with the same phenomena or measurement techniques.
<ul style="list-style-type: none">• Ensure that all personnel involved in every aspect of experimentation maintain their objectivity throughout the experiments. Under no circumstances should these people feel that they would ever be punished for failing to deliver or rewarded in any way for delivering the “right” results.
<ul style="list-style-type: none">• Be prepared to repeat experiments and iterate through the experimental process. Some early experiments, especially in a poorly understood area, may only identify what should not be done and cause redesign of the experiment. Some experiments may lead to additional experiments. Allow the schedule and budget for iteration and repetition where possible.

This guidance conveys convincing arguments against performing experiments at all. However, experimental data, if collected under well-controlled and applicable conditions, provides the best source of referents for poorly understood phenomena. This guidance applies equally well to the experiments conducted for results testing and to experiments from which to develop validation referents.

⁸ see the special topic on Risk and Its Impact on VV&A

How does one handle validation with limited experimental data (e.g., one test point)?

The cost and time required to conduct experimentation may limit the amount of experimental data available for validation. In this situation, the following options can augment experimental data in order to construct an adequate referent:

- use experimental data collected from other activities for similar situations
- use empirical data for similar situations
- extend the range of the experimental data with calculations from consistent and validated models of the underlying phenomena
- extend the range of the experimental data with the input from SMEs
- use data from consistent and validated simulations of components

The process of constructing referents should employ as many credible data sources as possible. Experimentation is but one source of data, and its feasibility determines the magnitude of its contribution to the referent data set for any application. Insufficient experimental data simply requires reliance upon other data sources. Merging multiple data sets from various sources into a single referent permits checking the consistency of each set against the others. That improves the credibility of the referent and the validation using it.

Limited experimental data can act as standard references against which to calibrate and control the fusion of information from the other sources. Using experimental data in this role can reduce the need for exhaustive experimentation, and it makes limited data sets useful. However, it requires the use of data from other sources and careful attention to the conditions under which the experiments were conducted to assure the applicability of that data.

Thus, a single experimental data point can support validation but not without credible data from other sources, and then only if the data point is consistent with data values from other sources. A single experimental data point can never satisfactorily validate a model or simulation for any purpose. In general, one should use extreme caution when extrapolating from a limited number of field tests to assess overall model validity.

What is the cost-benefit evaluation of data collection (cost vs. confidence)?

Experiments are generally the most costly means to develop referents, especially for models or simulations of complex systems or phenomena. As a result, this option should always be approached deliberately and through careful analysis and planning. Experiments provide the most benefit where

- other referents do not exist, conflict with or do not apply to the project because the conditions they cover differ from those addressed

- performing well-designed and sufficient experimentation falls within project cost and schedule constraints
- project risk depends the most upon the validity of simulation results
- experiments are being conducted for other purposes (e.g., test and evaluation), and the impact of including validation objectives is acceptable
- conducting selective experimentation is straightforward and has minimal costs
- selective experimentation can contribute the most to improving model or simulation validity where it is needed

The results from well-designed, carefully conducted, and relevant experiments carry the most weight in building the credibility of a model or simulation. Poorly designed, shoddily conducted, or irrelevant experimentation has the potential to do the most damage to a project by validating incorrect simulation results.

How should validation and test and evaluation (T&E) activities interact?

Validation and T&E activities complement each other in every way. Validation can provide information to help the design of T&E plans by identifying where system performance is most sensitive to the state of surrounding conditions and where uncertainties about system performance exist. This information can make testing more selective and thus reduce the cost and schedule required for T&E. T&E activities can supply data against which models and simulations can be validated (i.e., for their referents). This information can increase the quality of any validation results and reduce the cost and schedule required for V&V by reducing the effort needed to construct suitable referents (e.g., through separate experimentation). Planning the V&V and T&E activities together should increase their synergy. Additional information on the relationship between T&E and V&V activities is available in the reference document on T&E and V&V Integration.

Preparing Comparison Inputs

This section addresses issues in two basic categories:

- **Requirements Articulation**
 - [What roles does requirements specification play in validation](#)
 - [How should requirements be characterized for validation](#)
 - [How can testable requirements be developed](#)
 - [How should incompletely or informally defined representational requirements be treated](#)
- **M&S Characterization**

- [How should M&S elements be characterized for validation](#)
- [How should conceptual models be characterized for validation](#)
- [How should M&S data be characterized for validation?](#)
- [How should execution results be characterized for validation](#)

Requirements Articulation

What role does requirements specification play in validation?

A clear and complete statement of the requirements⁹ for a model or simulation is an absolutely necessary part of any validation process. Requirements represent the User's objectives for the model or simulation and define the purpose against which the model or simulation capabilities are compared to determine validity. Validation cannot be done without requirements; only an assessment of the model's or simulation's capabilities is possible.

How should requirements be characterized for validation?

The representational requirements for a model or simulation should be characterized in terms of their fidelity components. These components include the characteristics listed below:

Characteristics of Fidelity Components
• Object classes
• Maximum number of each object class
• Object properties
• Ranges of object properties
• Dependencies between the object properties
• Sensitivity of each independent variable of each object dependency
• Domain of each independent variable of each object dependency over which the required sensitivity should hold true
• Precision of each dependent variable of each object dependency
• Accuracy of each dependent variable of each object dependency
• Range of each dependent variable of each object dependency over which the required resolution and accuracy should hold true

The numeric characteristics listed in the table above (e.g., accuracy, range, etc.) should be defined by acceptable upper and lower bounds that describe the tolerances of the User's purpose. This characterization of requirements is generally quantitative and unambiguous. In addition, it simplifies the validation process by making straightforward and objective comparison with the model or simulation capabilities possible. The

⁹ see the special topic on Requirements for additional information

reference document [SIW Fidelity Report](#) further defines these components and discusses their roles in the validation process.

While the fidelity component characteristics list above suggests posing requirements in terms of objects and their characteristics, it does not imply the necessity for an object-oriented analysis and design process. This list uses the term “object” in a very general sense to mean something that is modeled or simulated. The term “object class” distinguishes the general nature that all simulated entities share from distinct instances of those entities being simulated at a particular time. Describing requirements in terms of represented object classes, their properties and dependencies specifies their content rather than the process used to obtain that content.

How can testable requirements be developed?

Testable requirements¹⁰ are key to making objective validity assessments. Testability means that the capabilities of a model or simulation can be unambiguously compared with the requirement to determine if the model or simulation can meet that requirement. Testable requirements require clear statements of the requirements and equally clear and compatible descriptions of the model’s or simulation’s capabilities. The aspect of testability implies that different people can compare a model’s capabilities against the requirements or different methods can be used to make the comparison and still arrive at consistent conclusions. Stating the representational requirements for an application in terms of the fidelity components described for requirements characterization is the first necessary step toward testable requirements. Stating the model’s or simulation’s capabilities in these same terms is the second necessary step. Informally stated requirements can be tested through SMEs, but the results may vary from individual to individual. This variation limits the credibility of the validation results.

How should incompletely or informally defined representational requirements be treated?

Complete and formal definition of all the requirements¹¹ may be infeasible due to cost or schedule constraints. As a practical matter, some amount of informality and incompleteness of the requirements statement should be tolerated. The key is to carefully identify which requirements need to be stated completely and formally.

Areas that make the greatest contributions to project risk identify those objects that a model or simulation needs to represent to best ameliorate that risk.

¹⁰ see the special topic on Requirements for additional information

¹¹ see the special topic on Requirements for additional information

Example:

If key project or application decisions depend upon knowledge of the behavior of specific objects or components, then to be useful, the simulation should provide insight into the character of those objects. The characteristics to which those decisions are most sensitive define the object properties to be represented and the accuracies with which they should be represented.

Decision sensitivities and the expected usage scenarios define the property and variable ranges and domains. Often the strengths of the dependencies between project decisions and risk enable prioritization of project decisions and, thus, requirements. Those representational requirements linked to the decisions with the highest priorities should receive the most effort to make them complete and formally stated. Harmon et al. [1999] defines the formal linkage between project or application risk, decisions and simulation requirements.

Informal requirements can also be treated by using SMEs with User credibility to make validity assessments. Agreement among multiple SMEs can further improve the credibility of validity assessments. Further, SMEs can even help to make informally stated requirements more concrete. However, this requires caution to prevent the SMEs from defining artificial preciseness just because they have been asked to do so.

M&S Characterization

How should M&S elements be characterized for validation?

The recommended validation process compares the capabilities provided by a model or simulation with the referents and the requirements. Thus, describing these capabilities in the same terms that describe the referents and the requirements simplifies this comparison and makes its results more reproducible. The same fidelity components used to characterize model or simulation requirements should be used to characterize the model's or simulation's capabilities whenever possible. See the section on [how requirements should be characterized for validation](#) and the [SIW Fidelity Report](#) for further definition of these components and their roles in the validation process.

Informally stated requirements or referent knowledge embedded in the expertise of SMEs require SMEs to perform the comparison necessary for validation. Thus, the capabilities of a model or simulation should be characterized in terms the available SMEs understand. The special topic on SMEs and VV&A provides more insight into this requirement and the limitations imposed upon SME choice and preparation. Other special cases are discussed in more detail below.

When the capabilities of a model or simulation are compared with experimental or empirical data or the results of another model or simulation, they should be stated in compatible form. Every step to translate capabilities, requirements or referent

information introduces another source of error. In some cases, this error can be extremely difficult to meaningfully quantify and control.

How should conceptual models be characterized for validation?

The DoD Modeling and Simulation Glossary [DMSO, 1997] defines the conceptual model and its components as follows:

conceptual model. A statement of the content and internal representations that is the User's and Developer's combined concept of the model. It includes logic and algorithms and explicitly recognizes assumptions and limitations

The special topic on conceptual models¹² provides further detail describing conceptual models, their contents and the processes supporting their construction. Conceptual models should describe their representational requirements/capabilities in terms of the fidelity components described in the section on [requirements characterization for validation](#) above and in the [SIW Fidelity Report](#). To evaluate a conceptual model the SMEs should either understand the language describing the conceptual model or have access to someone who can translate that language into terms the SMEs understand. This translation introduces another source of validation error. Reducing validation errors argues for describing conceptual models in plain language.

How should M&S data be characterized for validation?

In some cases, the data supporting a model or simulation should be characterized for validation. In these cases, the following comments guide their characterization to support the recommended validation process:

- If these data quantitatively describe characteristics of the simulated objects and dependencies between their property values, then those characteristics should be transformed into the terms described by the fidelity components given in the section on requirements [characterization for validation](#) and in the [SIW Fidelity Report](#).

This representation enables their meaningful comparison with the quantitatively stated requirement tolerances described above. This guidance also applies to the parts of knowledge bases for human behavior representations (HBRs)¹³ that lend themselves to quantitative characterization.

- If these data are compared to referents derived from experimental or empirical data, then they may need to be transformed to make this comparison possible.

Such transforms should ensure the consistency of all coordinate reference frames, statistical interpretations, measurement units, and analytical interpretations. The reference document on T&E and V&V Integration describes

¹² see the special topic on Conceptual Model Development and Validation

¹³ see the reference document on HBR Validation

the interactions between test and evaluation and validation activities and addresses these consistency issues in more detail.

- If the fidelity components cannot readily describe these data then they should be translated into terms that the available SMEs understand [understand [reference document [SIW Fidelity Report](#)]]. The special topic on SMEs and VV&A describes the limitations associated with SME interpretations and special topic on HBR Validation describes the details of using SMEs to validate HBR knowledge bases.
- If the data represent HBR knowledge bases that are stated in terms of a specialized programming language not readily understood by the available SMEs, then either the programming language representation should be translated into terms the SMEs understand by a software or knowledge engineer or the SMEs should be taught to interpret the programming language themselves.

Both of these approaches have been used successfully. However, the use of itinerate SMEs generally requires translation of the knowledge base contents by a resident member of the development team.¹⁴

These comments apply to situations where the data are included as part of the conceptual model or are evaluated separately. These comments do not imply that validation of a simulation's data, even the knowledge bases of HBRs, is ever sufficient to assess a simulation's validity. All data should be validated¹⁵ after they have been integrated in the simulation during results validation.

How should execution results be characterized for validation?

Ideally, the execution testing of a simulation will produce a detailed characterization of that simulation's functionality and performance in terms of the fidelity components described in the [SIW Fidelity Report](#). However, some simulations, especially those of human behavior representations (HBRs)¹⁶, do not produce such easily interpreted quantitative behavior. In addition, the instrumentation used to collect the results often limits the form that simulation results take. SMEs¹⁷ need to analyze subjective and qualitative results. This implies that those SMEs should understand any simulation results they are evaluating. If they do not, then a knowledgeable member of the development team should translate the execution results into an understandable form. This often occurs in the reasoning traces from HBRs

The conditions under which the simulation results were obtained need to be carefully and completely described. These conditions should be expressed in the same terms as

¹⁴ see the special topic on SMEs and VV&A and the reference document on HBR Validation for more information on this process

¹⁵ see the special topic on Data V&V for New Simulations

¹⁶ see the reference document on HBR Validation

¹⁷ see the special topic on SMEs and VV&A

used to describe the experimental conditions under which referent data were collected to make comparison of simulation results with the referents efficient. It is extremely important to make sure that the comparisons between simulation results and the referents or between the simulation results and the requirements be comparisons of the same things precisely. Any additional translation step required to make this assurance introduces the possibility of errors occurring. These errors, especially if poorly characterized, can severely diminish the credibility of the validation process and, thus, affect the perceived validity of the entire simulation.

Comparison Techniques

This section addresses issues in three basic categories

- **General Comparison Issues**
 - [What does comparing a simulation to its referent contribute](#)
 - [What does comparing a simulation to its requirements contribute](#)
 - [What comparison techniques exist for validation](#)
 - [What are the general limitations associated with the comparison techniques](#)
 - [Where in the V&V process do the different comparison techniques best apply](#)
 - [Where does data validation fit into the V&V process](#)
 - [What differences exist between formal and informal validation techniques](#)
 - [How can the products of informal techniques be improved](#)
 - [When should informal comparison techniques be chosen over formal techniques](#)
 - [What tools exist to support validation](#)
- **Comparison Technique Selection**
 - [How and when should SME assessments be used](#)
 - [How and when should audits, inspections, or walkthroughs be used](#)
 - [How and when should visual comparisons be used](#)
 - [How and when should analytical comparisons be used](#)
 - [How and when should formal comparisons be used](#)
- **Evaluating Comparison Results**
 - [When is model validity close enough for a particular purpose](#)
 - [What is the difference between face validity and results validity](#)
 - [How does sensitivity analysis apply to validation](#)

General Comparison Issues

What does comparing a model or simulation to its referent contribute to the validation process?

The referent for a model or simulation establishes the standard representing the real simuland (i.e., the things being modeled). Comparing the functionality and performance of a model or simulation against the referent identifies

- the amount that the model or simulation abstracts the simuland (i.e., level of detail or abstraction)
- the accuracy that the model or simulation provides over the abstracted range of simuland properties

Here, accuracy is the degree to which the values of the properties represented by the model or simulation agree with the values represented by the referent under identical conditions (i.e., the inverse of representational error). In other words, this comparison identifies how closely the model or simulation replicates the functionality and behavior of the simuland (or, at least, our best knowledge of the simuland). This information contributes to characterizing the fidelity capabilities of the model or simulation.

What does comparing a model or simulation to its requirements contribute to the validation process?

Comparing a model or simulation with its requirements determines how closely its capabilities come to supplying the behavior necessary to achieve the User's objectives. This comparison determines the validity of a model or simulation for the User's purposes.

What comparison techniques exist for validation?

Many different techniques¹⁸ exist for comparing a model or simulation to its referents and requirements for validation. These can be grouped into the following general classes:

- informal and structured assessments by SMEs
- audits, inspections, and walkthroughs
- visual comparisons
- analytical comparisons
- quantitative, formal, and statistical comparisons

¹⁸ see the reference document on V&V Techniques

Each of these classes contains one or more individual techniques that can vary in their design and application. The reference document on V&V Techniques provides an extensive list of techniques to support verification and validation and the special topic on Fidelity shows how different techniques contribute to model or simulation credibility.

What are the general limitations associated with the comparison techniques?

The table below describes the limitations associated with each class of comparison technique.

General Limitations of Different Comparison Techniques	
Comparison Technique Class	Limitations
SME assessments	<ul style="list-style-type: none"> • SMEs should be available & properly prepared • all information should be understandable to SMEs
Audits, inspections, & walkthroughs	<ul style="list-style-type: none"> • Teams should be properly composed, available, and prepared • sufficient information should be available for review sessions
Visual comparisons	<ul style="list-style-type: none"> • Information should lend itself to meaningful visualization • visualizations should be scaled correctly
Analytical comparisons	<ul style="list-style-type: none"> • Referents & requirements should be described in forms that permit comparison with model or simulation representations (e.g., UML)
Formal comparisons	<ul style="list-style-type: none"> • Information should take a formal, usually quantitative, form • uncertainties may need to be described but should absolutely be understood

The remaining issues of this section address these technique classes and their variants. Additional information is also available in the reference documents A Practitioner's Perspective on Validation, HBR Validation, and V&V Techniques; the special topic Fidelity; Harmon [1998].

Where in the V&V process do the different comparison techniques best apply?

The table below describes where in the V&V process each class of comparison technique best applies.

Steps in V&V Process where Comparison Techniques Best Apply	
Comparison Technique Class	Validation Process Step
SME assessments	<ul style="list-style-type: none"> • conceptual model, data & results validation
Audits, inspections, & walkthroughs	<ul style="list-style-type: none"> • conceptual model & data validation
Visual comparisons	<ul style="list-style-type: none"> • data & results validation
Analytical comparisons	<ul style="list-style-type: none"> • conceptual model & data validation
Formal comparisons	<ul style="list-style-type: none"> • conceptual model, data & results validation

In this table, the term **data validation** includes the issue of knowledge base validation as well as other forms of complex data that the conceptual model may not represent. This differentiation does not imply that data validation is ever sufficient for the validation of a model or simulation. All data, including the knowledge bases of human behavior representations, should ultimately be validated after being integrated within the simulation through results validation (see the special topic on Data V&V for new Simulations).

Where does data validation fit into the V&V process?

The simulation code interacts with its data during execution to produce its behavior. Data, in this context, include platform parameters, environmental databases, and human behavior representation (HBR) knowledge bases. These data can be extremely complex. Simulation execution with invalid data for a purpose can produce invalid behavior even though the simulation code is correct. Thus validation of various forms of data is an important intermediate step of the V&V process, although it is not explicitly described in the top-level process.

Data that are included in the conceptual model¹⁹ should be validated as part of that model with the same comparison techniques to ensure the consistency of results. Data that are not included as part of the conceptual model should be validated separately for the model's or simulation's purposes. This is often the case for HBR knowledge bases. Separate validation of data, particularly these knowledge bases, simplifies the interpretation of the simulation's results and provides insight crucial to simulation debugging. Data verification²⁰ for consistency and coherence is equally important, but it is a separate process, often employing different tools and techniques.

What differences exist between formal and informal validation techniques?

Informal validation techniques usually

- require only qualitative information about the models, referents, and requirements, although they may use quantitative information
- use loosely constrained, and possibly defined, processes for comparing that information

Some informal techniques employ structured processes that consist of unambiguously defined steps and identify specific data requirements (e.g., through questions, tables or matrices). Informal comparison techniques, while appearing easier to execute, often produce only opinions that depend solely upon the credibility of their sources. Well-qualified and prepared sources (e.g., SMEs) can deliver excellent opinions but they

¹⁹ see the special topic on Conceptual Model Development and Validation

²⁰ see the special topic on Data V&V for New Simulations

remain opinions nonetheless. Different, equally qualified sources can provide disparate, sometimes irreconcilable, validation opinions about the very same aspects. Further, in many cases the assumptions underlying the results from informal techniques range from obscure to unknown. Poorly understood assumptions always diminish the credibility of validation results.

Formal validation techniques generally

- require quantitative information about models, referents, and requirements
- use mathematically precise processes for comparing that information

The processes of formal techniques are formally derived, through some form of logic, from a well-defined set of propositions that rigorously define the assumptions that should hold for the process to produce correct results. These assumptions may strongly limit the applicability of a technique to a narrow range of situations and data quality. Formal techniques can also require more effort execute manually than informal techniques unless they are supported by automation. However, formal techniques lend themselves to automation more readily than informal techniques. Careful employment of formal techniques can generate results with considerably more correctness and reproducibility than informal techniques. However, the ultimate credibility of formal techniques for validation depends strongly upon the trust that a User has in the technique and the precision of its execution. Incorrectly applied formal techniques can deliver incorrect results that masquerade as correct.

How can the products of informal techniques be improved?

The effort required and strict limits of applicability of formal techniques may force the use of informal techniques for validation. Informal techniques can produce results of acceptable quality for many validation applications. The quality of results from informal comparisons can be improved in several ways:

Ways to Improve Quality of Results from Informal Comparison
• Using several sources with complementary backgrounds and forcing them to develop consensus opinions can improve the credibility and reproducibility of the comparison results.
• Using structured techniques can reduce the subjectivity of expert opinions but seldom, if ever, completely resolve it. In some cases, technique structuring only gives the illusion of rigor and well-defined assumptions.
• Carefully defining the assumptions associated with an informal technique can more clearly define the limits of the applicability of its results.
• Repeating an informal comparison using different expert sources can provide information about the nature of any variability that may exist and so help define credibility limits.
• Using a well-defined technique that the information sources have used many times can improve the completeness and repeatability of its results.

When should informal comparison techniques be chosen over formal techniques?

Several situations, shown in the table below, exist when informal techniques that compare a model or simulation with its referents or requirements should be chosen over formal techniques:

When to Choose Informal Techniques over Formal Techniques
When no formal techniques apply to the situation. <ul style="list-style-type: none">• Do not use a formal technique outside the limits of applicability defined by its assumptions. This only gives the illusion of credibility.
When model, referent, or requirement characterizations cannot be put into a comparable form using a formal technique. <ul style="list-style-type: none">• Informal characterization transformations introduce assumptions and, possibly, errors that the formal comparison technique will amplify.
When no people are available who have in-depth understanding of the assumptions and technique derivations. <ul style="list-style-type: none">• A formal technique is credible only if it is applied correctly. A poorly understood formal technique should not be used because it will surely be used incorrectly, thus giving incorrect results.
When schedule and cost constraints limit the effort for validation comparisons. <ul style="list-style-type: none">• A shoddily applied formal technique delivers poorer results than a more carefully applied informal technique.
When formal techniques generally require tedious attention to detail that only automation can help. Often a single mistake can jeopardize all of the results. <ul style="list-style-type: none">• Informal techniques, especially if adequately structured, are usually less sensitive to individual mistakes.

Finally, using informal techniques for validation is always better than performing no validation because the budget did not exist to support a correctly applied formal technique.

What tools exist to support validation?

Although many tools²¹ exist to support verification, at the time of this writing, relatively few tools exist to support formal validation. This situation will improve over time as the theory underlying validation evolves toward maturity. Then, the particular nature of useful tools will become clearer. However, because the field is advancing so rapidly, monitoring the availability of validation tools at the Defense Modeling and Simulation Office (DMSO), particularly the Modeling and Simulation Resource Repository (MSRR), can prove fruitful.

²¹ see the reference document on V&V Tools

Comparison Technique Selection

How and when should SME assessments be used?

Subject matter experts (SMEs) can provide requirements and referent characterizations and participate in comparing a model or simulation to them. SMEs can validate conceptual models, knowledge bases or data, and simulation results. SMEs should be used when

- there are SMEs available with the appropriate expertise, particularly if they can be assigned continuously to the project
- informal comparison techniques should be employed
- the Users believe strongly in the credibility of SMEs and their ability to represent User requirements
- User requirements are imprecisely stated or poorly understood

Section 4.2 of A Practitioner's Perspective on Simulation Validation and the special topic on SMEs and VV&A provide more detailed guidance for using SMEs.

How and when should audits, inspections, or walkthroughs be used?

Audits, inspections, and structured walkthroughs are particularly useful in validating conceptual models and knowledge bases. They can also be helpful in trying to understand invalid simulation results. These informal structured techniques should always be used in conceptual model validation where possible. They should be applied to knowledge base validation where

- economics and schedule permit
- enough people are available who understand the semantics of the knowledge base
- the complexity of the knowledge base forces it to be developed by several individuals

Structured informal techniques usually carry more overhead than unstructured techniques but provide the basis for considerably more credibility and reproducibility. Their structure may help to hasten the understanding of results that another technique detected as invalid.

Section 4.6 of A Practitioner's Perspective on Simulation Validation provides an extensive description of structured walkthroughs. The reference document on V&V Techniques provides helpful information about several informal structured techniques.

How and when should visual comparisons be used?

Visualization techniques can help to detect invalid simulation results and can support credibility [section 4.9, A Practitioner's Perspective on Simulation Validation]. Visualization techniques can only be used when the information is in the right form for the available technique. Further, extreme care should be used when using visualization to determine validity to assure that such factors as scaling and optical illusions do not affect the decisions. Invalid behavior can appear valid under the right image scaling. Visualization techniques possess the potential to be extremely useful to validation of simulations of complex phenomena but can only reach that potential with the use of the correct tools. As of this writing, these tools have only been developed for a small set of phenomena (e.g., computational fluid dynamics).

Rigorous visualization techniques can be most readily applied to the comparison of quantitative simulation results and examination of such large quantitative databases as terrain models. Behavior visualization techniques can greatly help SMEs examine simulation results, particularly for simulations with which they can interact in real time. However, in this application of visualization, extreme care should be taken to avoid the contamination of the SME validation decisions by visual anomalies. Insufficient display resolution and scaling problems often lead to incorrect assessments from visual displays. Software visualization techniques are evolving to where they may soon apply to conceptual model and knowledge base validation. Until these visualization techniques have reached a wider state of practice, however, it is probably a good idea to use them to support other comparison techniques.

Section 4.9 of A Practitioner's Perspective on Simulation Validation provides more information about the types and use of visualization for validation.

How and when should analytical comparisons be used?

Analytical comparison techniques examine the structure and causality of models and simulations through detailed and rigorous analysis procedures (e.g., causal analysis, semantic analysis, structural analysis, fault analysis). These techniques are often supported by such visualization techniques as flow charts, entity-relationship diagrams, Petri nets, and object diagrams. The reference document on V&V Techniques and special topic on Fidelity both explain and compare these techniques.

Analytical comparison techniques lend themselves particularly well to conceptual model and knowledge base validation. Several techniques have been applied for these purposes²². Analytical techniques can also be useful in understanding the root causes of invalid results. However, the extent of their rigor and detail may make them poor choices for initially detecting invalid behavior.

²² see the reference documents on HBR Validation and V&V Techniques and the special topic on , Conceptual Model Development and Validation

How and when should formal comparisons be used?

Formal techniques can provide extremely powerful arguments to support credibility but their well-defined ranges of suitability and strict information content requirements may limit their application. Formal techniques can be used in conceptual model, knowledge base, and results validation. In general, formal or quantitative techniques should be used whenever possible and suitable²³. Some of the conditions needed to make the situation suitable for formal techniques are shown below:

Conditions for Using Formal Techniques
• simulation, referent and requirements characterizations need to have the correct semantics and syntax to suit the technique
• assumptions of the technique need to match both the representational requirements and implementation circumstances of the simulation
• people are available who thoroughly understand the technique and its application
• Users trust the credibility of the technique

The reference documents on A Practitioner's Perspective on Simulation Validation and Statistical Concepts and Methods provide more insight into using quantitative and formal techniques. The special topics on Fidelity and V&V Techniques compare various formal techniques and the [SIW Fidelity Report](#) defines model, simulation, referent and requirements characterizations that support the application of formal and quantitative comparisons for validation.

Evaluating Comparison Results

When is model validity close enough for a particular purpose?

Model or simulation validity is close enough for a particular application when the User believes it to have sufficient credibility for their purposes. The special topic on Fidelity describes the many factors that influence credibility. Validation provides only one piece to the argument supporting model or simulation credibility. Cost and schedule constraints may also moderate the level of validation desired. However, no model or simulation can truly be credible without validation in some form.

More specifically, a model or simulation is valid enough for a particular purpose when its representational capabilities fall within the representational tolerances posed by the requirements. The [SIW Fidelity Report](#) rigorously defines this condition in terms of measurable fidelity components for both model or simulation capabilities and requirements. However, this quantitative measure of "close enough" only works for quantitatively stated representational requirements.

²³ see the reference document on A Practitioner's Perspective on Simulation Validation

Qualitatively stated requirements should either be refined to precision through iteration with the User²⁴ or be evaluated by a User representative such as an SME. In attempting to create precise representational requirements, one should beware of creating artificial precision where none really exists. Faithful but imprecise requirements are far better than precisely stated requirements that inaccurately represent the User's real needs. When SMEs act as the User's representatives, then "close enough" is when they agree that the model or simulation has sufficient validity to adequately serve the User's purposes.

What is the difference between face validity and results validity?

A model or simulation has **face validity** if the SMEs reviewing the capabilities characterization decide that it looks valid enough for the intended purpose. This decision may come from review of the conceptual model, knowledge base, or simulation results. A simulation has results validity when testing has provided sufficient results to assure that it meets a purpose's representational requirements. This decision may come from any one or a combination of the comparison techniques discussed above including SME comparisons. Face validity may contribute to results validation but is seldom sufficient by itself. Face validation and results validation are discussed in greater detail in A Practitioner's Perspective on Simulation Validation and Conceptual Model Development and Validation.

How does sensitivity analysis apply to validation?

Sensitivity analysis determines how much the values of a function's dependent variables vary with changes in its independent variables. Sensitivity analysis has several applications to validation, including

- identifying validation priorities by determining upon which simulation capabilities a project's risk most depends
- identifying validation priorities by determining those simulation dependencies that depend most strongly upon their boundary conditions
- identifying regions where validation is most needed by determining where simulation dependencies vary the most

The reference documents on A Practitioner's Perspective on Simulation Validation and Statistical Concepts and Methods discuss sensitivity analysis and its applications to validation in greater detail.

²⁴ see the reference document on A Practitioner's Perspective on Simulation Validation

Validation Planning and Management

This section discusses issues in the following categories

- **Management Issues**
 - How can the effort needed for validation be justified
 - What is the relationship between risk and validation
 - What is the relationship between confidence, credibility and validation
 - How can management expectations of validation be managed
 - How can changing validation requirements be managed
 - How can validation priorities be set
- **Validation Planning Issues**
 - What parts of a model or simulation should be validated
 - Where in the V&V process should a model or simulation be validated
 - How can the costs for validation be estimated
 - How can information resource limitations be overcome
 - When can information from previous V&V efforts be used
 - When can the experience from previous applications of a simulation be applied to validation
 - How can project time constraints and schedule conflicts affecting validation be managed
- **Scenario Concerns**
 - What effects does the design of execution scenarios have upon simulation validity
 - What role does scenario design have in results validation
 - What factors should contribute to designing scenarios to support results validation
- **Special Validation Problems**
 - How can invalid behavior be handled
 - How can simulations of very complex phenomena be validated
 - How should compositions of simulations be validated

Management Issues

How can the effort needed for validation be justified?

The validation of a model or simulation serves two important purposes to any project:

- providing the evidence to establish the model's or simulation's credibility for a particular purpose
- providing information that defines the limits of a model's or simulation's fitness for a purpose and, through knowledge of those limits, contributing to project risk reduction

A model or simulation that has not been validated for the User's particular purposes cannot reasonably be considered credible and cannot contribute to risk reduction. These purposes establish the basis for any argument justifying the validation necessary for a model or simulation. The special topic on Fidelity discusses the links between validation and credibility in greater detail and Harmon et al. [1999] shows how validation contributes to risk reduction. A Practitioner's Perspective suggests further informal argument supporting validation. Additional discussions below outline the links between validation, risk, and credibility.

What is the relationship between risk and validation?

Project [risk](#)²⁵ depends upon the probability of errors occurring that can adversely affect fully achieving the project objectives. Knowledge about the causes of potential project errors reduces the probability of those errors occurring. Models and simulations represent one source of that knowledge. However, use of either irrelevant or incorrect knowledge for project decisions can actually increase the probability of project failure. In fact, the use of a single piece of incorrect knowledge can assure project failure, although no single piece of correct knowledge can assure project success. Validation reduces the likelihood of models and simulations generating incorrect and irrelevant knowledge for project decisions. Therefore, they contribute to assuring the use of only correct knowledge. This is essentially how validation contributes to reducing project risk.

Harmon et al. [1999] elaborates this basic argument and identifies specific areas where validation is most effective. The special topic on Risk and Its Impact on VV&A discusses how to manage the risk of V&V efforts to prevent their introducing project errors.

What is the relationship between confidence, credibility, and validation?

Validation contributes evidence to support model or simulation credibility. The weight of this evidence improves confidence in the model or simulation by defining

- the limits over which it can create valid representations for a particular purpose
- the specific meaning of validity for that purpose

²⁵ see the special topic on Risk and Its Impact on VV&A

Knowing the limits of model or simulation validity can help guide its use and the design of execution scenarios that take best advantage of its capabilities. The User's purposes, and the requirements derived from those purposes, establish the meaning of validity for a particular model or simulation. Knowing this helps identify the specific information that can be trusted from a model or simulation.

The confidence or weight of validation evidence can be improved by

- obtaining results validation data that agree with conceptual model and knowledge base validation data
- obtaining validation results that agree with results from past validation efforts upon the same model or simulation under suitably similar conditions
- obtaining independent SME validation assessments that agree with each other and other validation results
- obtaining validation results that agree from the independent application of different techniques to the same model or simulation under the same conditions
- choosing and carefully executing structured informal techniques over simple informal validation techniques
- choosing and appropriately applying quantitative characterizations and formal validation techniques over qualitative characterizations and informal validation techniques

The special topic on Fidelity discusses the dependencies between credibility and validation in greater detail.

How can management expectations of validation be managed?

An M&S PM's expectations of any validation effort can best be managed by ensuring that they know

- exactly what they are getting from the effort
- what the cost and schedule impacts are for that effort

Examples of these are shown in the following tables:

Typical M&S PM Expectations from Validation
Requirements that characterize the User's purposes and objectives
Nature of the referents used to characterize the simuland
Techniques chosen for validation and where in the process they should be applied
Parts of the model or simulation that will and will not be validated

Typical M&S PM Expectations from Validation
Conditions under which the validation results hold true
Sensitivity of the validation results to changes in the evaluation conditions
Assumptions and limitations associated with characterizations of the model, referent, and requirements and the techniques employed for validation
Contingency plans and the events that invoke them
Validation results

Information Included in Cost and Schedule Impacts
Cost and schedule requirements for a baseline minimal validation effort and what kind and quality of information that effort delivers
Cost and schedule requirements for any enhancements to the baseline validation effort and what benefits those enhancements provide
Cost and schedule requirements of any planned contingency efforts
Prioritization of the enhancements and contingency plans
Other resource constraints (e.g., SMEs with particular expertise and availability) for baseline and each enhancement
Cost, schedule, resource, and prioritization impacts of any changes due to requirements or project changes for both baseline and enhancements.

Expectation management should occur continuously throughout the project and intensify at the beginning of each phase of the validation process. No new phase of the validation effort should be entered or significantly changed without the M&S PM knowing exactly what they are getting and what it will cost them. A Practitioner's Perspective on Simulation Validation discusses additional factors associated with interfacing with the decision-maker on a regular basis that aid managing manager expectations.

How can changing validation requirements be managed?

Modeling and simulation requirements changes can cause changes in

- validation priorities
- what parts of a model to be validated
- referents to be used
- model, referent, and requirement characterizations to be used
- applicable comparison techniques
- cost and schedule impacts of the validation effort

Requirements changes can be managed by understanding the

- dependencies between User's objectives and each detailed requirement and its priority
- dependencies between the detailed requirements and each choice of referent, characterization approach, and comparison technique
- dependencies between the requirement priorities and the validation effort priorities
- limitations and assumptions of the characterization approach and comparison techniques chosen
- dependencies between cost and schedule impacts and the validation choices made

This knowledge can be used to assess the impact of any requirements changes upon the validation effort and to re-plan the validation effort to accommodate those changes. Having well-characterized contingency plans can also help manage requirements changes.

How can validation priorities be set?

Validation priorities should be set based upon the risk²⁶ associated with the information that models and simulations provide to support project decisions. Therefore, the following suggestions can guide the setting of validation priorities:

Suggestions for Setting of Validation Priorities
• Set validation priorities highest for models and simulations that provide information to those project decisions upon which the success of the project depends most sensitively.
• Set validation priorities higher for project decisions that depend solely upon modeling and simulation for their information than for those that rely upon multiple independent sources of information.
• Set validation priorities higher for information upon which the correctness of project decisions depends most strongly than for information to which the correctness of project decisions is less sensitive.
• Set validation priorities higher for the information whose correctness (in the context of the project requirements) is most sensitive to changes in simulated conditions than for information less sensitive to simulated conditions.

Harmon et al. [1999] and the special topic on Risk and Its Impact on VV&A provide more detail about the nature and rationale for these suggestions. The reference documents A Practitioner's Perspective on Simulation Validation and Statistical Methods and Concepts discuss sensitivity analysis in detail.

²⁶ see the special topic on Risk and Its Impact on VV&A

Validation Planning Issues

What parts of a model or simulation should be validated?

The following suggestions guide identifying what parts of a model or simulation to validate:

Validation Suggestions
Validate those parts of a model or simulation upon which the User's purposes depend most strongly. <ul style="list-style-type: none">• helps establish the model or simulation credibility for those purposes
Validate the simulated objects, object properties, and object dependencies that the User uses most often. <ul style="list-style-type: none">• assures that the User is not constantly reminded of inadequate validation that may make the simulation unsuitable for their purposes
Validate under those conditions where the most simulated objects or object properties can interact. <ul style="list-style-type: none">• complex interactions can hide invalid behavior from casual examination
Validate in those regions where simulated object dependencies are chaotic, stochastic, or nonlinear. <ul style="list-style-type: none">• These conditions increase the amount of detail needed to make accurate validation decisions

These suggestions can help to reduce the size and complexity of the validation effort.

Where in the V&V process should a model or simulation be validated?

Detailed validation of the conceptual model and knowledge bases can significantly reduce the errors incorporated into the development process, which, in turn, can reduce both the cost of developing the right simulation for a User and the risk that the wrong simulation will be developed. Validating the conceptual model before development begins helps ensure that the Developer thoroughly understands the User's requirements and begins development on the right foot. Validating knowledge bases reduces the errors incorporated into the representations of such complex process as human behavior and the difficulty of diagnosing the results validation errors discovered during testing.

Although none of the validation tasks performed early in the V&V process reduces the importance of results testing and validation, they should reduce the amount of effort required to diagnose any problems found during results validation and the amount of effort required to repair problems found in verifying and validating a simulation implementation. Early validation steps also provide information that can help to focus the results validation effort on the most important parts of the simulation. Incremental validation deals with a simulation at stages of gradually increasing complexity.

Postponing validation until after the simulation implementation is completed (i.e., results validation) creates the most difficult possible situation and may result in the entire simulation effort failing to meet the User's objectives. An integrated validation effort that executes all of the validation steps greatly increases the likelihood that the simulation will deliver the desired product within its cost and schedule constraints.

All this said, certain practical difficulties can reduce the amount of early validation that is possible:

Conditions Affecting Validation
Poorly stated requirements <ul style="list-style-type: none">• Often requirements become more clearly defined as a project evolves and the development effort discovers the limits of feasibility.
Limited availability of necessary resources <ul style="list-style-type: none">• The appropriate SMEs may not be available in the early stages of the project, or their availability may limit the amount of conceptual model and knowledge base validation possible.
Limited availability of model or simulation information <ul style="list-style-type: none">• Certain development paradigms design and implement simulations incrementally. In those cases, conceptual models and knowledge bases may also be developed incrementally, leaving no choice but to validate these incremental but incomplete products when they become available. However, the temptation to ignore or neglect conceptual model development in these situations should be avoided.
Limited funding for early validation <ul style="list-style-type: none">• Many project-funding profiles delay substantial funding for development activities. This funding strategy may leave early validation efforts under-funded. The only choice here is to prioritize the validation requirements and concentrate upon the most important ones.

All of these conditions tend to push the validation effort into results validation; however, none of them reduces the amount of validation necessary. That is determined solely by the User's objectives and the complexity of the simulation. If any of these conditions, or any others, impacts an otherwise reasonable validation plan, then the results validation effort, cost, and schedule should be rescoped to account for the additional validation needed at that stage.

How can the costs for validation be estimated?

Validation costs depend directly upon the requirements and the simulation's complexity. Validation costs increase with the

- number of different types of objects, object properties, and object dependencies required
- narrowness of the required tolerances upon the fidelity of the object dependency behavior

- simulation computational complexity (e.g., number of object dependencies represented)
- incorporated representations of nonlinear, chaotic or stochastic behavior
- implementation complexity (e.g., number of different execution platforms and communications links between them)

Additional factors that can also change validation costs include

- SME availability
- referent data availability (e.g., experimental data)
- particular comparison techniques trusted as credible by the User
- funding for early validation

In short, any factors that limit the resources necessary to perform adequate validation activities can increase the ultimate validation costs. The special topic on Cost describes how to calculate validation costs more specifically.

How can information resource limitations be overcome?

The table below summarizes the types of information needed to support validation and the possible sources of that information.

Requirements and Sources of Validation Information	
Validation Information Requirement	Information Sources
Requirements	<ul style="list-style-type: none"> • SMEs, other User representatives, User documentation (e.g., concepts of operations)
Referents	<ul style="list-style-type: none"> • SMEs, existing system documentation, experimental data, analysis & study reports
Model/simulation	<ul style="list-style-type: none"> • conceptual model, design documentation, development team members
Comparison techniques	<ul style="list-style-type: none"> • RPG, technical papers, SMEs

Ideally, the information to support validation should come from multiple independent sources. This permits checking the consistency and correctness of information. It also enables the strengths of one source to overcome the deficiencies of other sources. Information resource limitations can also limit the comparison techniques that can be used. For example, the lack of quantitative information describing requirements, referents, or model capabilities can make the use of formal comparison techniques difficult and force reliance upon SME assessments.

The assessment and management of information resource limitations should be approached systematically:

- identify the types of information required for validation
- assess the availability of information sources and the type and quality of information they can supply
- compare the availability of information with the information requirements to identify unmet information requirements
- map the needs to the available resources and identify resource contingencies to overcome any problems encountered later

When can information from previous V&V efforts be used?

The information generated by previous V&V efforts on a model or simulation can greatly reduce the effort required to validate a model or simulation for a new purpose by providing all of the components needed for validation. Despite its attractiveness, the use of previously gathered validation information should be approached cautiously:

- **Examine the specifics of the representational requirements and compare them with those of the new application.**

Only the information directly related to equal or identical requirements can be used. However, requirements with overlapping tolerances may also be comparable enough to be useful. Obviously, any requirements for the new application with no counterparts from previous uses should be explored anew.

- **Identify the impacts of any modifications to the model or simulation.**

Small modifications to critical parts of a simulation (e.g., the simulation engine) may force complete revalidation because they broadly affect the simulation's representational capabilities. Similarly, modifications to representational elements that interact with a large number of other simulated entities may need broad validation because of the ability to spread the effects of these modifications through causality. On the other hand, small changes to isolated models may require minimal effort to make information from previous validation efforts applicable.

- **Ensure that the operating conditions of the previous applications are similar to those for the new application.**

Operating conditions include the execution environment, scenarios, databases, and the other simulations with which the one being validated interacts.

- Changes in the computing platform, communications resources and operating system can dramatically affect the execution properties and representational capabilities of a simulation.

- Changes in the scenarios, databases, and interactions may drive a simulation over parts of its representational space that have not been explored by previous validation efforts or use.

Sensitivity analysis may help identify where validation is needed to extend the results of previous efforts.

- **Investigate the processes, tools, and people that produced the previous validation results.**

Many processes and tools encompass assumptions that may limit the applicability of any results they produce. These underlying assumptions may not be clearly articulated in the validation documentation. In some cases, the people using them may not have understood their limitations. In addition, the limitations of the people, including SMEs, may reduce or restrict the applicability of the validation results they produced. This is particularly true if the new application differs significantly from previous uses. Validation can be subjective in many ways, and the extent of this subjectivity can affect the applicability of existing validation results.

Rarely will following these recommendations lead to completely discarding previous validation evidence. Existing validation information can always provide insight into an application or a simulation. However, these recommendations should discourage blithely assuming that the results of previous validation efforts are both useful and correct.

When can the experience from previous applications of a simulation be applied to validation?

Previous applications of a simulation can provide a valuable source of validation information and support the credibility of the simulation to the User. Usage primarily helps to characterize the capabilities of a simulation and, thus, can supplement results validation. However, before employing this information, the conditions surrounding previous uses should be completely understood. Scanty documentation of the purpose and conditions of the previous applications may hamper gaining this understanding.

Determining how the new application differs from previous usage is particularly important because those differences will define the extent to which prior experience is applicable. Subjective evidence on the success of previous applications should be most carefully examined. Such evidence often contributes more to credibility beliefs than to establishing a simulation's validity, especially for a new application. While such perceptions are indisputably important, they should not be substituted for a carefully planned and executed validation process.

How can project time constraints and schedule conflicts affecting validation be managed?

Validation time constraints and schedule conflicts arise most often because many projects consider V&V activities to parallel the development effort. This means that the pace of the development effort and schedule set the pace for the validation effort. As a result, the validation effort should be planned to synchronize with the development effort schedule. Specific points that dictate the synchronization come from

- the information required from the development effort for validation
- the development effort release dates

At some points in the schedule, the validation will require information from the development team (e.g., conceptual model description). At other points, the development schedule will determine the amount of time available for a particular validation activity (e.g., conceptual model and results validation). Time limitations, as well as information availability, helps determine the choices of characterization approaches and comparison techniques. Careful validation planning that synchronizes with the development plan can circumvent many problems encountered due to time and schedule constraints. This planning should also identify activity contingencies at each point of interaction between the development and validation efforts. These contingencies facilitate modifying the validation plan to accommodate changes in the development plan.

Scenario Concerns

What effects does the design of execution scenarios have upon simulation validity?

The design of execution scenarios can greatly affect the validity of simulation results. An execution scenario defines the envelopes in the simulated world within which the simulation will operate to serve a particular purpose. All models and simulations have limited ranges and domains over which their fidelity can be predicted²⁷. Operating simulations outside these ranges and domains can produce results with less fidelity or, worse, with unpredictable fidelity. Thus, their validity, for a particular purpose, may be less than desired or may be unpredictable. Simulation scenarios should be carefully designed to avoid areas of the simulation space where unpredictable and invalid behavior may result. In some cases, a simulation that does not generally meet the fidelity requirements to support a particular purpose can satisfy those requirements for limited scenarios.

²⁷ see the reference paper on the SIW Fidelity Report

Careful scenario design also limits the amount of results validation that may be necessary by reducing the space over which the simulation should be tested. This is especially true for simulations of complex phenomena (e.g., human behavior representations²⁸, synthetic environments).

What role does scenario design have in results validation?

The scenarios supporting simulation testing determine what parts of the simulation machinery will be tested and how much the testing will exercise that machinery. Thus, scenario design directly affects what results the testing activities will produce for validation. Therefore, results validation depends heavily upon scenario design. Scenarios that exercise the simulation in regions where it behaves well will theoretically produce valid results. On the other hand, scenarios that visit regions beyond the bounds of good simulation behavior produce invalid or unpredictable results. Good scenarios produce testing results that sample a simulation's behavior enough to enable accurate assessments of a simulation's validity for some application. A simulation with poorly understood behavior requires scenario designs that generate enough data to sufficiently characterize those regions where a simulation behaves well and poorly. In addition, testing scenarios can help to overcome the difficulties of testing simulations of such complex phenomena as human behavior²⁹.

What factors should contribute to designing scenarios to support results validation?

The scenarios supporting results validation determine

- what parts of the simulation will be exercised
- under what conditions that exercise will take place
- where and what results data will be collected during the testing

Therefore, these scenarios should exercise those parts of the simulation required to accomplish the objectives listed below:

Objectives to be Addressed by Scenarios
• achieve the application's objectives
• understand those parts of the simulation least well understood and relevant to the application
• sufficiently characterize the behavior of the simulation that the application will use most and that, therefore, can be expected to have the greatest probability of errors occurring
• sufficiently explore those parts of the simulation that can manifest the most complex behavior where potential errors can hide

²⁸ see the special topic on HBR Validation

²⁹ see the special topic on HBR Validation

Objectives to be Addressed by Scenarios
<ul style="list-style-type: none">• identify where simulation behavior is simplest and most predictable and, thus, where sparse sampling is adequate
<ul style="list-style-type: none">• provide meaningful data points that can be compared with such referents as experimental data
<ul style="list-style-type: none">• sufficiently characterize the sensitivity of the simulation's behavior to the different conditions under which it is operating
<ul style="list-style-type: none">• sufficiently characterize the probability distributions representing areas where the simulation's behavior is stochastic

Special Validation Problems

How can invalid behavior be handled?

All models and simulations have limited abilities to recreate reality, which limits their validity for some applications. Validation activities should discover these limits as they apply to a purpose and characterize them. This information permits

- construction of scenarios to avoid areas that could provide unacceptably incorrect results
- use of other simulations or information sources to provide supplementary information where simulation validity is weak
- enhancement of the simulation to overcome the validity limitations pertinent to the application

How can simulations of very complex phenomena be validated?

Simulations of complex phenomena such as environments (e.g., terrain, weather, ocean) and humans (both individuals and groups) present special problems, particularly in managing validation complexity and choosing the appropriate referents. Validation complexity can be managed by

- validating only where and to the degree that the application requires (don't validate any more than necessary)
- using conceptual model and data (e.g., knowledge base) validation to focus results testing by identifying areas of poorly understood or complex behavior

Referents for complex system validation should

- provide information relevant to the application at hand and nothing more
- come from multiple sources so that their consistency can be checked

- be chosen to represent those areas where the application is most sensitive to the simulation results

How should combinations of simulations, such as high-level architecture (HLA) federations, be validated?

Like complex phenomena, simulation compositions present special validation problems. To date, the validation of simulation compositions is not well understood. This means that reliable validity assessments can only come from validating the results generated by the composition in its complete form. Any change in the composition or the configuration of its components calls for revalidation through results testing. The results from validating the components of these compositions can help to guide testing of the composition but cannot contribute directly to assessing the validity of that composition. Despite hopes to the contrary, the following truths apply to composition validation:

Truths That Apply to Composition Validation
<ul style="list-style-type: none">• The combination of two invalid simulations can never produce a composition with valid behavior (i.e., two wrongs never make a right)
<ul style="list-style-type: none">• A single invalid simulation can endanger the validity of all simulations that depend upon interactions with it (i.e., a single wrong can even make rights wrong)
<ul style="list-style-type: none">• The combination of two individually valid simulations does not necessarily produce a composition with valid behavior (i.e., two rights do not always make a right)

These truths suggest that all of the simulations within a composition should always be operated within their valid regions and, even then, the composition may not produce valid behavior. As a result, until the behavior of simulation compositions are better understood, their validation should rely upon results testing.

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