Key Concepts of VV&A

DoD VV&A RPG

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This document corresponds to the web version of the VV&A RPG Menu Item of the same name and date. It has been modified to make it suitable for printing.

Introduction

The Department of Defense (DoD) and the military services have recognized the growing significance of modeling and simulation for many aspects of their operations, and have prepared directives and guidelines to provide general instructions on how, when, and under what circumstances formal VV&A procedures should be employed. This Recommended Practices Guide (RPG) is intended to facilitate the application of those directives and guidelines, and to promote the effective application of VV&A.

The RPG describes the interrelated processes that make up VV&A from a number of perspectives. Different sections of the RPG cover the different roles and responsibilities of the various participants; discuss special topics associated with VV&A; identify tools and techniques, and provide reference material on related areas. This document continues with an informal discussion of the key concepts of VV&A – the principles, rationale, terminology, and general approach to conducting VV&A for models and simulations. It provides an analogy from everyday life intended to demonstrate the practicality of VV&A and concludes with a summary of the costs and benefits and an introduction to the remainder of the RPG.

What, in general, is VV&A?

Why is VV&A performed?

To determine whether a model or simulation or federation should be used in a given situation, its ***credibility*** must be established by evaluating ***fitness*** for the intended use. In simplest terms, verification, validation, and accreditation (VV&A) are three interrelated but distinct processes that gather and evaluate evidence to determine, based on the simulation's intended use, the simulation's capabilities, limitations, and performance relative to the real-world objects it simulations. The decision to use the simulation[1] will depend on the simulation's capabilities and correctness, the accuracy of its results, and its usability in the specified application.

The purpose of VV&A is to assure development of correct and valid simulations and to provide simulation users with sufficient information to determine if the simulation can meet their needs. VV&A processes are performed to establish the credibility of the models and simulations. Credibility depends on simulation ***capability*** – not in an absolute sense, but relative to the capabilities needed for the specified application. Credibility also depends on the ***accuracy***[2] of a simulation – not in an absolute sense, but relative to the accuracy necessary for the intended use. The decision on whether or not a simulation provides the necessary degree of accuracy depends not only upon the inherent characteristics of the simulation, but also upon how the simulation will be used, and upon the significance of any decisions that may be reached on the basis of the simulation's outputs.

> Example:
>
> A command and control (C2) training exercise in which computer simulated tanks are mixed with live tanks needs to have a very accurate visual representation of the tank so participants cannot tell which is which. A simulation using the same scenario in an analysis of alternatives (AoA) would not need the high level of visual representation but would need a high level of accuracy in attrition output, etc.

Credibility for a simulation also depends (in part) on its ***correctness***[3], the level of confidence that its data and algorithms are sound and robust and properly implemented, and that the accuracy of the simulation results will not substantially and unexpectedly deviate from the expected degree of accuracy. Credibility depends, as well, on its ***usability*** -- factors related to the use of the simulation, such as the training and experience of those who operate it, the quality and appropriateness of the data used in its application, and the configuration control procedures applied to it.

Because so many of the factors just described are situation-dependent, there cannot be a simple "yes/no" decision that will apply in all circumstances wherein a simulation might be used. Just because a simulation is judged suitable for one purpose in one organization does not automatically guarantee that it would be suitable for the same type of use in some other organization, nor even that it would be suitable for some other type of use within that same organization.

[1] Throughout this Guide, the term "simulation" will be used as a general descriptor for model, simulation, and federation.
[2] Accuracy: The degree of exactness of a model or simulation. High accuracy implies low error. Accuracy equates to the quality of a result, and is distinguished from precision, which relates to the quality of the operation by which the result is obtained and can be repeated. [RPG Glossary]
[3] Correctness in this context refers to the condition of code, software, and data, e.g., error-free code, appropriate authoritative input data.

That being said, a decision that a simulation has been used for a specific purpose by one organization may well be taken as important evidence to consider by another organization that wants to use a simulation for a similar purpose.

> Example:
>
> An organization is considering a choice between the use of two technically similar models or simulations. If one has a lengthy history of comparable uses in other organizations without major problems and the other is new and untried, then the organization should expect that the second to require more extensive V&V and testing than the first before being judged “credible” for the intended use.

VV&A is performed when the potential risk of making an incorrect decision based on a simulation outweighs the time and cost of performing VV&A to ensure that simulation can produce results that are sufficiently accurate and reliable. Performing the VV&A processes creates a sound basis for the organization to proceed to the next stage of a project, and to determine how much to rely on the simulation within the project. Also, VV&A can help determine whether there is a need to further investigate the simulation to mitigate risk, and, if necessary, whether to take preventive action to resolve any risk areas before any adverse impacts could occur.

Why is VV&A important?

VV&A derives its importance from the intended use of the simulation to which it will be applied. For example, if a simulation is to be used for training purposes, then the importance of VV&A depends on the importance of the activity for which the training is being conducted, the degree of accuracy required for the training to be effective, and the expected degree of difficulty for the developer of the simulation in achieving that accuracy.

> Example:
>
> Performing VV&A for a simulator used to train helicopter pilots for landing on the deck of a destroyer in heavy seas would be comparatively more important than VV&A for training the operators of fork lifts for moving cargo on a supply ship.
>
> Both are important, but the helicopter landing situation involves much greater risk to the safety of military personnel, involves significantly more expensive equipment, is much more likely to have a direct impact on a military objective in a combat situation, and is a far more difficult situation to simulate with fidelity.

Similarly, the appropriate extent of VV&A performed for a simulation used for assessment will depend on the budgetary considerations and the significance of any decisions that will be based on the use of the simulation, as well as on the risk of inaccuracy inherent in the problem representation being used.

> Example:
>
> A frequent DoD application for modeling and simulation (M&S) is in the concept evaluation, design, and manufacturing or construction of a weapons system. For this use it is necessary (among other things) to document the requirements and intended usage for a system, determine whether the functional system design can in principle meet these requirements, confirm that the specific design values selected for critical system attributes are sufficient for the system to achieve its required performance, and then to determine if the selected values for these attributes are technically achievable at an affordable cost.
>
> The nature of the system being designed will determine, in part, the methods that can be used to confirm the reasonableness of the design values, and the types of simulations that can be used for this purpose. The decision quality benefits will occur primarily in two areas: avoiding (or minimizing) the risk of making bad choices based on simulation data, and providing support for decisions concerning whether to use simulation data or to pursue, instead, analysis based on other engineering approaches.

When a simulation is employed as one of the means to confirm the suitability of the design values chosen, then the validation of the simulation's results takes on significance commensurate with the impact on the anticipated performance of the system, and with the strategic or military significance of the system.

> Example:
>
> All things being equal in terms of simulation difficulty and technical uncertainty, a performance simulation for an expensive weapons system upgrade that could have a significant impact on military superiority would warrant a more in-depth VV&A effort than a simulation used to evaluate an inexpensive new weapons system design that could yield limited cost reductions but could not otherwise have much impact (either positive or negative) on military effectiveness.

The increasing reliance on modeling and simulation within the acquisition process also increases the financial and safety risks from erroneous or inaccurate simulation results. Further, the availability of a definitive V&V record can help technical managers decide whether or not to try to use – or modify and re-use – an existing simulation rather than undertake development of yet another new one. Good V&V increases the potential for cost savings from software re-use. These factors are driving the increased DoD emphasis on VV&A.

Finally, special VV&A considerations apply when a simulation may be used as a substitute for some prototype field testing or live fire testing. Here, the importance of VV&A and the extent of VV&A necessary depend on the significance of the live test being replaced by a simulated test. History provides numerous examples of the importance of thorough testing, and unfortunately, more than a few examples of what can go wrong when testing is inadequate. Simulation use can help to identify essential areas for testing and help prioritize testing resource use.

Example:

The Mars Climate Orbiter was lost due, in part, to a "lack of complete end-to-end verification of navigation software and related computer models" [Mars Climate Orbiter Release].

When the Hubble Space Telescope was being constructed, a decision was made to save costs by not assembling it on the ground to check all the alignments before sending it into space. After launch "…NASA announced that the telescope suffered from spherical aberration … the problem concerned two excellent yet mismatched mirrors …" [Hubble Space Telescope].

This led to over a 3½-year delay in achieving the Hubble's intended operating capabilities. Finally, an in-space repair mission was necessary: "Successful completion of the first refurbishment mission in December 1993 … restored most of the planned capabilities …" [Hubble Space Telescope].

Such problems are not limited only to today's highly complex systems.

Example:

The U.S. entered World War II with a submarine fleet that was dangerously ineffective. Their primary weapon, the Mark 14 torpedo had not been (live fire) tested since 1926, despite the incorporation of a new, advanced exploder design in 1934 [Torpedoes of WWII]. The live fire tests had also been extremely limited in number and had yielded only a 50% success rate – i.e., one out of two test shots was successful. Further, the torpedoes had never been live fire tested against the types of surface ship targets for which they were intended. Nevertheless, thousands were built based on this limited testing.

There were three serious design flaws, which were not found and corrected until midway through the war. Thus, it was not until half of the entire war in the Pacific that the U.S. submarine fleet was able to become fully effective.

Example:

The Army Air Corps in World War II had a not-dissimilar problem with its 500 lb. bombs, which were not exploding reliably on the hard (coral) surfaces of many Pacific islands. Field modifications to the fuze were required to solve the problem[4]. Untested prioritization rules implemented at Navy repair depots during World War II caused the "disappearance" of critical radar components in short supply. They were later found on trains, shuttling back and forth across the country.[5]

What does all this system testing experience have to do with VV&A for M&S? Only this: Simulation is much more economical than live fire testing and field testing. In the future, live fire tests and field tests will be increasingly supplemented with simulated tests. If the simulations used do not have sufficient ***fidelity*** to represent the actual military systems in the types of environments where those systems will be used, then the simulated test results will be questionable. It is easy to envision, as a result of the increasing reliance on simulated tests, that a system design flaw could remain hidden

[4] Based on conversation with an observer of the live test drops conducted to diagnose the problem.
[5] Based on conversation with an individual involved in tracking down the missing components.

for years if a simulation designer did not anticipate all the important possibilities and incorporate them into the simulation. There is an ever-present and increasing risk that simulated tests might not reveal design flaws in future weapons systems because, as history demonstrates, they can and do result from *unanticipated* interactions between system components and the operating environment. The increasing role of models and simulations to support testing will place even a greater importance on the role of VV&A.

In summary, the larger issues of weapons system deployment and use, in combination with the technical characteristics of the simulation and the level of confidence in its input data and other operating parameters, should determine the level of risk to be assigned to the simulation for which VV&A is being undertaken. This level of risk, combined with the potential military impacts of the system, will determine the ideal level of effort that should be expended for VV&A. Like most everything else in a development program, the use of VV&A is an economic decision. Is there risk of loss in the use of this simulation without further VV&A? That is the essential economic question for VV&A.

What are the key considerations for scoping the VV&A effort?

The objective of VV&A is to collect a body of evidence to establish the credibility of a simulation for a certain, specified use. This is best accomplished as a continuing activity, conducted *as part of* the overall process of developing and preparing a simulation for use (see the section on When is VV&A performed? [p. 9]).

The specific details of the V&V process actually employed will, of course, vary with the nature of the simulation and its intended application.

> Example:
>
> The V&V approach for a training simulation for a weapons system operator must necessarily focus on the realism of the immediate responses of the system's controls to operator actions within a simulated situation in a simulated environment.
>
> In contrast, the V&V of an analysis or assessment simulation for that same weapons system might well focus upon the accuracy of the representation for weapons effectiveness against selected threats, and might also be concerned with the representation of longer time-frame impacts such as demands placed on the logistics support system.

The key point here is that the V&V approach must be ***tailored*** to match the nature of the problem, which includes not only the situation(s) being simulated but also the types of decisions that are driving the employment of the simulation. Additional factors concern the nature of the simulation. The use of human-in-the-loop (HITL) or hardware-in-the-loop (HWITL) components, different types of simulation (e.g., new, legacy, federation) require somewhat specialized treatments. Even for the same type of simulation, every situation will be somewhat different from the one before, so no rigid "cookbook" VV&A process can fit all situations all the time. Therefore, tailoring the V&V effort is an essential part of the V&V process itself.

Finally, specific elements of the V&V approach will be selected based upon the ***level of risk*** understood to be inherent in the decision being supported by the simulation, the criticality of the simulation results to the decision being reached, and the availability of time, money, and personnel to execute V&V.

Technical or resource limitations may mandate that the V&V processes be tailored, in practice, in a way that is less than ideal from a purely VV&A perspective. All of these factors, including any limitations placed on the V&V activity due to time or resources, must be taken into account by the Accreditation Authority when reaching a conclusion for the approval or disapproval of the use of the simulation.

Trade-off agreements that reduce the level of V&V performed should be reached in light of what is best for the program being supported, but the broader context of the long-term use (reuse) of the simulation should be considered as well. Decisions to limit the V&V effort may save money for the immediate program (as well as introduce some degree of risk), but these decisions also limit the chances of simulation reuse, resulting in higher costs for other programs, which may not, in the final analysis, be the best option.

What, specifically, is VV&A?

What are the core processes of VV&A?

VV&A incorporates three distinct processes: verification, validation, and accreditation. The formal definitions for these processes are given in the box below:

> Definitions for verification, validation, and accreditation from DoD Instruction (DoDI) 5000.61 [DoDI 5000.61]:
>
> **Verification** - The process of determining that a model implementation and its associated data accurately represent the developer's conceptual description and specifications.
>
> **Validation** - The process of determining the degree to which a model and its associated data provide an accurate representation of the real world from the perspective of the intended uses of the model.
>
> **Accreditation** - The official certification that a model, simulation, or federation of models and simulations and its associated data is acceptable for use for a specific purpose.

It can also be helpful to remember each one in terms of simple question that (informally) captures the essential idea:

- **Verification** – *Did I build the thing right?*
- **Validation** – *Did I build the right thing?*

- **Accreditation** - *Should it be used?*

Also, there is an underlying implicit principle, and its key question:

- **Credibility** – *Should it be trusted?*

An accreditation decision reflects a determination that the evidence supporting a decision on whether and "how" to employ a simulation is strong enough to warrant putting that conclusion in writing and creating an official record of the decision – something not to be taken lightly.

Why not just validate? Why is verification needed as well?

Before continuing with the description of VV&A, it is important to address, and put to rest, a question commonly asked by those new to VV&A:

> If ***validation*** determines the degree to which a model and its associated data provide an accurate representation of the real world, and if that degree of accuracy is deemed sufficient to warrant either limited or full accreditation, then why is it viewed as necessary, or even desirable, to expend resources to first conduct a ***verification*** process? Why isn't validation, by itself, enough?

The implicit argument is that if a simulation works acceptably well (i.e., that it is proven to be the "right model", addressing the "validation" question) then this must also imply that either simulation was necessarily developed properly (i.e., that it was "modeled right", therefore also answering the "verification" question) or that proper development isn't important. This is not a bad argument, and if it were practical or even possible to test the full range of situations that might occur in a simulation, then this might reasonably be considered to be an acceptable argument. However, such comprehensive testing is – in general – neither affordable nor feasible.

As a practical matter, it could be unwise to undertake a validation exercise without first being assured that the simulation about to be validated works and does what is expected. Waiting until the (results) validation phase, after the simulation has been developed, to discover that it does not address the requirements means not only that a lot of resources and time have been wasted, but that it may be too late to correct the problem.

It is commonly understood in the software engineering community that the earlier problems are detected, the lower the costs involved in correcting them. In addition, verification helps provide an assurance that a simulation will not exhibit unrealistic or unstable behavior in those areas that are not or cannot be tested, contributing to the overall credibility of the simulation.

Example:

If the requirements demand an accurate simulation representation over some parametric region, and if the specifications do not indicate any reason to expect inconsistent behavior within that region (i.e., they do not contain equations or other features that might be unstable, chaotic in nature, etc.), then a *verification* that the simulation is an adequate implementation of the specifications will go a long way toward providing confidence that a simulation will perform in a reasonable and predictable manner.

Conversely, if the mathematical algorithms have certain ranges of parameters where the inherent mathematical behavior becomes unstable or undefined, or if the software implementation should have some inherent limitations that may cause the computed values to deviate from the purely mathematical results over some parameter regions, then one can expect that the simulation might not be reliable over these ranges of input values.

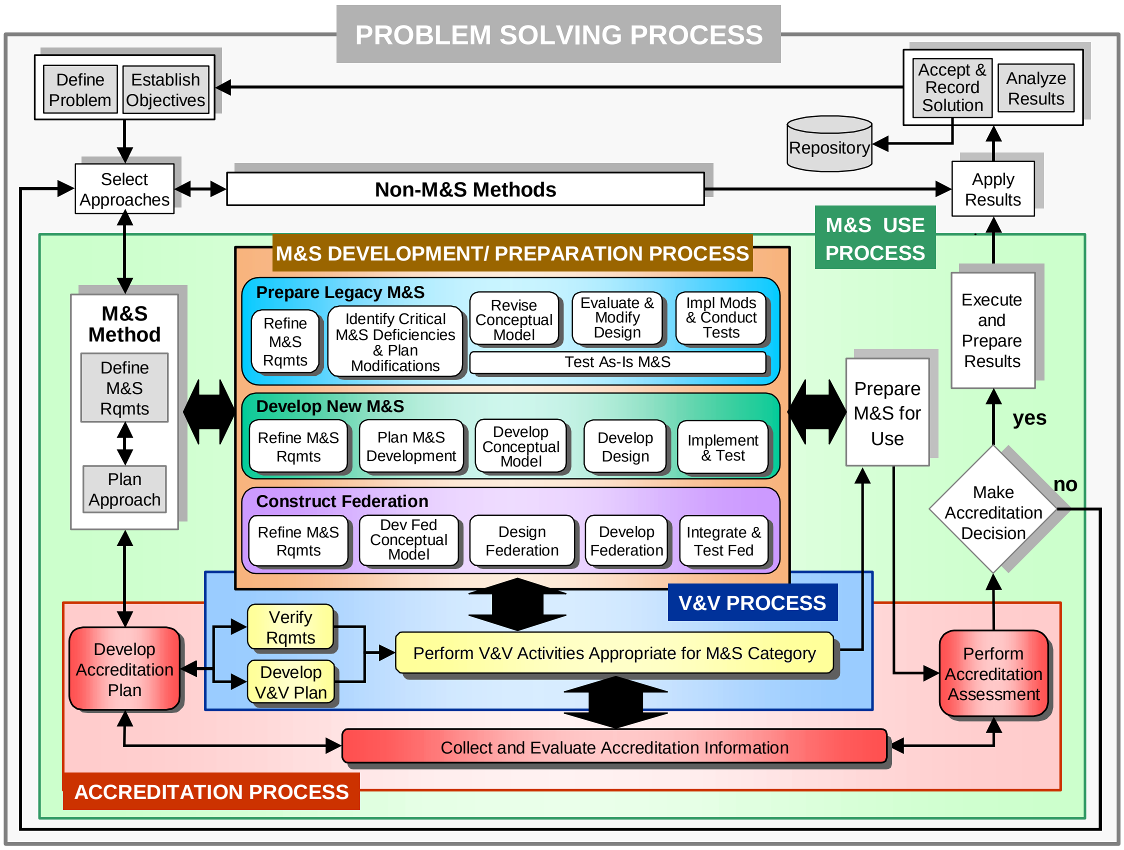
The verification effort can also help identify problem parametric regions so they can be avoided (i.e., they would be identified as simulation constraints or limitations).

Verification permits leveraging the materials already prepared by the developer in a way that validation usually does not, and provides the foundation upon which validation is based. Verification establishes the relationships between the requirements of the problem and the developmental artifacts (i.e., conceptual model, design, code) that are examined in testing and validation. There may be instances where it is simpler and less costly to undertake a relatively comprehensive validation effort rather than to perform verification, but these will be the rare exception, rather than the rule. Performing (rather than skipping) verification will lead to increased confidence in the V&V results, and in most cases will yield a *lower* overall cost for conducting the full VV&A process.

When is VV&A performed? What tasks must be accomplished for effective VV&A?

VV&A is best accomplished as a continuing activity, conducted *as part of* the overall process of developing and preparing a simulation for use. The life cycle of a simulation, its development, use, modification, and reuse, always occurs within the context of its use. A simulation is developed for a specific purpose (e.g., pilot training, analysis of alternatives of artillery munitions, concept development for a sensor), but it may be reused for other purposes in other applications. The simulation's life cycle continues through phases of modification and reuse as long as it is deemed fit to address some problem.

The purpose of VV&A is to establish the simulation's fitness for each problem it is asked to address. Thus, VV&A helps establish the relationship between the problem and the simulation being used to solve it. The overall ***Problem Solving Process***, shown below, illustrates this relationship of interrelated processes as a series of nested boxes, each containing additional boxes representing the basic activities and functions that comprise that particular process.



The Overall Problem Solving Process

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The basic processes illustrated in this diagram are listed below and described in the following paragraphs

- Problem Solving Process – Instigation
- M&S Use Process -- Ingress
- M&S Development and Preparation Process
- V&V Process
- Accreditation Process
- M&S Use Process – Egress
- Problem Solving Process -- Conclusion

Problem Solving Process -- Instigation

The Problem Solving Process begins with two critical activities, defining the problem and selecting the approach for resolving it.

Problem Solving Problem: Define the Problem and Establish Objectives

The problem statement identifies the issues to be resolved, defines the objectives to be met, and establishes the scope and conditions under which the problem should be addressed. The problem and objectives need to be articulated clearly enough that decisions can be made about how to solve the problem and requirements--those aspects, features, conditions or characteristics that need to be addressed in the solution can be defined. Problem definition is critical to a successful solution. For complex problems, a formal problem analysis[6] can provide the guidance needed to select appropriate methods and establishes a firm foundation upon which the rest of the overall process can build.

Problem Solving Problem: Select Approach(es)

Modeling and simulation is but one method,[7] albeit an important one, for obtaining information needed to solve a problem or support a decision. The decision to use a simulation should be governed by the careful definition of the problem being addressed and the identification of the requirements needed for its resolution. Not every problem requires or even benefits from using simulation. However, it does offer certain advantages such as

- **Repeatability--** Important aspects of the real world can be recreated as if the actual event or operation were taking place (e.g., training an Army brigade)
- **Control --** An event or operation can be replicated under controlled conditions (e.g., running excursions of a battle to analyze the impact of different weapon systems)
- **Safety --** The capabilities of a system can be tested or experienced without expending actual resources (e.g., evaluating the action of a warhead fuse for an air-to-air missile)
- **Speed --** The important aspects of an event or operation can be conducted in less than real time (e.g., running a theater-level deployment exercise for a peacekeeping mission)
- **Reduced costs --** The potential success of a hypothetical weapon system under various battle circumstances can be explored before resources are allocated for its actual development

The decision to use M&S should not be taken lightly. A preliminary feasibility study should be performed to determine if it is reasonable and appropriate.

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[6] See the special topic on Problem Analysis for additional information.

[7] Other methods of obtaining information, used either instead of or in addition to simulation, include gaming, field testing, experiments, and the analysis of historical data, statistics, or data collected from direct observations or surveys.

M&S Use Process -- Ingress

When modeling and simulation has been selected as a solution approach, the next phase of the process is the M&S Use Process. All of the activities, functions, and nested processes in this process are directly associated with selecting, preparing, and executing (i.e., using) a simulation in support of the problem solving process. The activities at the beginning are extremely critical because they lay the foundation for the subsequent Development/Preparation Process and the supporting V&V and Accreditation Processes.

M&S Use Process: Define M&S Requirements

Once the decision is made to use modeling and simulation, the part simulation is to play in obtaining a solution should be more precisely defined. The M&S function is characterized as a set of M&S requirements[8] developed by addressing such issues as

- Which particular aspects of the problem will be addressed by the model or simulation (i.e., what is the specific application)?
- What requirements need to be met to find a solution? What aspects of the problem domain need to be addressed? What characteristics of the user domain need to be included?
- What capabilities does the model or simulation need in order to address these issues?
- What decisions will be made on the basis of M&S results?
- What are the ramifications of improper modeling? What risks are involved if erroneous results are accepted?
- What ***acceptability criteria*** are used to determine when success has been achieved?

M&S Use Process: Plan Approach

Planning the approach involves a number of decisions and tasks.

- **Select Simulation Type** -- Once the basic M&S requirements are known, the type of simulation to use must be determined. In some instances, a ***new (stand-alone) simulation*** may need to be developed; in other situations a ***federation*** may be the most appropriate method. Frequently, reusing a ***legacy simulation***, with or without modification, is the most economical and efficient approach.

  Normally, the decision of whether to use a federation or a stand-alone simulation is decided by the nature of the problem. Determining whether to use a legacy

[8] See the special topic on Requirements for additional information.

simulation, if one exists, or develop a new simulation is a business decision that should be based on a number of different factors affecting the overall costs involved and the level of risk incurred. When considering the use of a legacy simulation, there may be an additional task of evaluating different candidates to determine which is most appropriate for the current application.

- **Designate Participants** – Depending on the magnitude of the simulation effort involved, a number of different roles need to be filled: In addition to the ***User***, who is responsible for defining the problem and making the accreditation decision, the basic roles include:
  - ***M&S Program Manager (PM)*** -- planning and resourcing simulation development, overseeing preparation of the simulation for use, configuration management and simulation maintenance
  - ***Developer*** – designing and implementing the code
  - ***V&V Agent*** –accumulating evidence of the simulation's fitness by performing V&V activities
  - ***Accreditation Agent*** -- conducting the accreditation assessment

  Additional information about the various roles and their responsibilities can be found in the section on key players (p. 17).
- **Establish Overall Strategy** – define the responsibilities and interactions of the participants, establish milestones, identify artifacts and products, designate formats and reporting structures, establish configuration control methods, etc.

M&S Development and Preparation Process

The M&S Development/Preparation Process encompasses all the activities needed to develop, modify, and otherwise prepare a simulation for a specific use. Three basic subprocesses are involved, based on the types of simulation involved. Once simulation type has been determined, the appropriate subprocess is implemented.

M&S Development and Preparation Process: Develop New M&S

The advantage to developing a new simulation is that it is designed and built specifically to address the needs of the current application.[9] A major challenge is to ensure that the M&S requirements are specified sufficiently and captured properly in the conceptual model. This process consists of five basic activities, each of which results in a critical artifact or product:

- **Refine M&S Requirements** – results in the total set of detailed ***M&S requirements*** that the simulation needs to address.

[9] See the RPG diagram on VV&A for New Simulations for additional information.

- **Develop Conceptual Model** – results in the ***conceptual model***,[10] the collection of information that describes the Developer's concept about the simulation and its constituent parts. It serves as a bridge between the Developer and the User, demonstrating the Developer's understanding of the intended application.
- **Develop Design** – results in the ***design specifications***, a translation of the information captured in the conceptual model to support their implementation in software and hardware.
- **Implement and Test** – realizes the design in hardware and software (***code***) and ***test results*** pertaining to the individual components, data, and their integration.

M&S Development and Preparation Process: Prepare Legacy M&S

A ***legacy M&S*** is any M&S that was developed either in the past or for a different purpose. The emphasis in preparing a legacy simulation for use is the identification of critical deficiencies with respect to the current problem.[11] Deficiencies are discovered in part by examining the major development artifacts (M&S requirements, conceptual model, design, code, testing results) and other documentation (VV&A history, usage documentation).

If no deficiencies are involved (i.e., no code or hardware changes), then the simulation can be used ***as is***. When deficiencies are involved, the simulation should be modified to resolve the deficiencies and the simulation artifacts updated. A distinction is usually made between significant or ***major modifications*** and ***minor modifications***. Major modifications involve replacing or adding 30% or more of the code. The size and complexity of this much change usually requires the services of both a Developer and M&S PM. Minor modifications involve adding or fixing less that 30% of the code and usually do not require an M&S PM. Many minor modifications are even handled "in house."

M&S Development and Preparation Process: Construct Federation

Identification of the federates and their individual responsibilities is a major focus of federation design.[12] Emphasis is placed on the realistic portrayal of federate capabilities in carrying out the proposed responsibilities within the federation.

V&V Process

The nature in the V&V process depends on which type of simulation involved. The basic V&V activities apply to all three simulation categories; however, the relative importance of each activity and the specific tasks performed depend greatly on the type of simulation and the specifics of the application.

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[10] See the special topic on Conceptual Model Development and Validation for additional information.
[11] See the RPG diagram on VV&A for Legacy Simulations for additional information.
[12] See the RPG diagram on VV&A for Federations for additional information.

- **Verify Requirements** – confirming that the requirements for the simulation match those needed for the current problem, and are correct, consistent, clear, and complete.
- **Develop V&V Plan –** identifying the objectives, priorities, tasks, and products of the V&V effort; establishing schedules; allocating resources; etc.
- **Perform V&V Activities Appropriate for M&S Category** – selecting the activities and tasks that best suit the needs of the current application. Normally this involves some level of effort evaluating the artifacts of the simulation:
  - ***Validate Conceptual Model*** – confirming that the capabilities indicated in the conceptual model embody all the capabilities necessary to meet the requirements.
  - ***Verify Design*** – determining that the design is faithful to the conceptual model, and contains all the elements necessary to provide all needed capabilities without adding unneeded capabilities.
  - ***Verify Implementation*** – determining that the code is correct and is implemented correctly on the hardware.
  - ***Validate Results*** – determining the extent to which the simulation addresses the requirements of the intended use.

  Additional activities tasks are included as needed based on the simulation category and the needs of the application.

In simulation, it is virtually impossible to separately evaluate a model and the data it uses (e.g., input data, hard-wired data)[13] because it is the interaction of data and code that produces simulation results, making both responsible for simulation credibility. This mutual dependency suggests that data V&V activities should be considered part of the overall V&V process. Indeed, data V&V activities are discussed as part of the V&V process throughout the RPG. However, because of the large number of data categories used in a simulation and the amount of time needed to locate and acquire individual data sets, data V&V has a very unique nature.

- data V&V tasks are conducted on different sets of data
- different data V&V tasks may be required for different sets of data
- different techniques and tools may be needed to conduct data V&V tasks on different sets of data
- different data sets are obtained at different times
- the people performing data V&V activities frequently require different qualifications (e.g., SMEs with expertise in individual data areas)

[13] See the reference document on M&S Data Concepts and Terms for additional information.

Regardless of who conducts data V&V activities, they should work closely with those modifying and/or preparing the simulation for use and with those performing M&S V&V activities and the data V&V activities should be carefully documented and included in the V&V report. Additional information on data V&V is provided in three special topics: *Data V&V for New M&S*, *Data V&V for Legacy Simulations*, and *Data V&V for Federations*.

Accreditation Process

Accreditation is the official certification that a simulation and its associated data are fit for use in the specified application.

- **Develop Accreditation Plan** – the accreditation plan should identify all the information needed to perform the accreditation assessment, schedules, resources, etc. to be used in the accreditation assessment.
- **Collect and Evaluate Accreditation Information** – the information needed for the assessment is collected from the V&V effort and other sources and evaluated to determine its completeness.
- **Perform Accreditation Assessment** – the fitness of the simulation is assessed using all the evidence collected from the V&V effort and other sources and an accreditation report and recommendations are prepared for the User.

Although accreditation is often perceived as occurring at the end of a development process, the actual assessment process should begin as early as possible so V&V activities and testing activities can be sure of providing appropriate and sufficient information to support the accreditation decision.

M&S Use Process -- Egress

Once the accreditation process is completed, the process returns to complete the M&S Use Process Phase.

M&S Use Process: Make Accreditation Decision

The accreditation decision is essentially the User's belief in the credibility of the simulation. The V&V effort and the accreditation assessment are both done to amass evidence to show what risks are associated with using the simulation and how likely or unlikely they are to occur. The User weighs the risks against the evidence of the simulation's capabilities. There are basically five different options to consider:

- ***Full accreditation –*** using the simulation as is (accepting the risks)
- ***Limited accreditation –*** constraining the application to minimize the risks
- ***Modification of the simulation is needed –*** requiring corrections to be made that can reduce the risk even though they increase costs and cause delays

- ***Additional information is needed –*** requiring more information in order to understand the risks involved and instill confidence in the simulation's fitness before making a decision
- ***No accreditation –*** deciding that the risks involved in using the simulation and the costs involved in fixing it are both too great

When no accreditation is deemed possible, the User must select a different method to solve the problem. When the User decides additional work or information is needed, the process returns to the planning stage to establish a new plan to accomplish necessary work.

M&S Use Process: Execute and Prepare Results

When accreditation, either full or limited is selected, the simulation is executed and results analyzed and prepared for use.

Problem Solving Process -- Conclusion

The simulation results and combined with the results of any other methods involved in solving the problem. Analysis is conducted and conclusions are drawn. When the User is satisfied with the solution, the results are documented, reported and archived.

Who are the "key players" involved in VV&A?

Proper execution of a VV&A process involves participants in a number of different roles. Although these roles can be identified by different titles and their responsibilities can be divided in different ways, the RPG has designated five basic terms to describe the basic roles and responsibilities involved.

- **User.** ***User*** is the term used throughout the RPG to represent the organization, group, or person responsible for the overall application. The User has a problem to solve or a decision to make and wants to use simulation to solve it. The User defines the requirements, establishes the criteria by which simulation fitness will be assessed, makes the accreditation decision, and ultimately accepts the results.
- **Developer**. The ***Developer*** is the role responsible for actually constructing or modifying the simulation
- **Modeling and Simulation Program Manager (M&S PM).** The ***M&S PM*** is the role responsible for planning and managing resources, directing the overall effort, and performing configuration management and maintenance of the simulation.

- **Verification and Validation Agent (V&V Agent)**. The ***V&V Agent*** is the role that is responsible for providing evidence of the simulation's fitness for the current use by ensuring that all the V&V tasks are properly carried out.
- **Accreditation Agent**. The ***Accreditation Agent*** is the role responsible for conducting the accreditation assessment. The Accreditation Agent provides guidance to the V&V Agent to ensure that all the necessary evidence is obtained, collects and assesses the evidence, and provides the results to the User, the role with the responsibility of making the accreditation decision (i.e., accreditation authority).

In addition, ***Subject Matter Expert*** (SME) is an auxiliary role that contributes to the VV&A effort in a number of ways. An SME is an individual who is recognized as an authority in specific area. Expert opinions may be needed in a variety of different areas in a given application, ranging from aspects of the problem domain being simulated to the data and computing technology needed by the simulation. SMEs can be called upon to help in a variety of ways from helping the User in establishing requirements and acceptability criteria to participating in validation and accreditation assessment activities.[14]

The responsibilities for these roles, in relationship to VV&A activities, are illustrated in the table below. The left-hand column lists the basic activities involved in the development, preparation, and VV&A of new and legacy simulations and federations. The remaining columns identify the normal part each role plays in that activity. For large programs, each role is normally filled by a different person, group, or organization. For smaller projects, one person, group, or organization might perform several of these roles, or possibly even all of them.

Typical Roles and Responsibilities Associated with M&S VV&A

Role / Activity	User	M&S PM	Developer	V&V Agent	Accreditation Agent	SME
Define Requirements	Lead Approve	Monitor	Assist	Review	Review	Assist
Define Measures	Lead Approve	Monitor	Assist	Assist	Assist	Assist
Define Acceptability Criteria	Assist Approve	Monitor	Assist	Assist	Lead	Assist
Plan M&S Development or Modification*	Assist	Lead Approve	Assist	Assist		
Develop V&V Plans	Review	Assist Approve	Review	Lead	Assist	
Develop Accreditation Plan	Review Approve	Assist		Assist	Lead	

[14] See the special topic on Subject Matter Experts and VV&A for additional information.

Typical Roles and Responsibilities Associated with M&S VV&A

Activity \ Role	User	M&S PM	Developer	V&V Agent	Accreditation Agent	SME
Verify Requirements	Lead-alt Approve	Monitor	Assist	Lead	Assist	Assist
Develop Conceptual Model**	Assist Approve	Monitor	Lead			Assist
Validate Conceptual Model	Assist Approve	Monitor	Assist	Lead		Assist
Develop Design***		Monitor Approve	Perform			
Verify Design	Approve	Monitor	Assist	Lead		Assist
Implement Design		Monitor Approve	Perform			
V&V Data	Approve	Monitor	Assist	Lead		Perform
Verify Implementation	Approve	Monitor	Assist	Lead		Assist
Test Implementation	Approve	Monitor	Lead	Assist		Assist
Validate Results	Assist Approve	Monitor	Assist	Lead		Assist
Prepare V&V Report				Perform		
Configure for Use	Assist	Lead Approve	Assist			
Gather Additional Accreditation Info	Monitor	Assist		Assist	Lead	Assist
Conduct Accreditation Assessment	Monitor				Perform	Assist
Prepare Accreditation Assessment Report					Perform	
Determine Accreditation	Perform					
Prepare Accreditation Report					Perform	

Lead	Leads the task. Normally involves active participation from others
Perform	Actually does the task. Normally involves little active participation from others
Assist	Actively participates in task (e.g., conducting tests, providing information)
Review	Participation normally limited to reviewing results of task and providing recommendations
Monitor	Oversees task to ensure it is done appropriately but does not normally participate
Approve	Determines when an activity is satisfactorily completed and another can begin. Determines what activity should be pursued next (e.g., whether to continue on to the next scheduled activity or to return to a previous activity).

*This activity refers to planning and scheduling of any M&S development, modification, or preparation

**This activity refers to development of new as well as modification of existing conceptual models

***This activity refers to development of new M&S designs as well as modification of existing M&S designs

Detailed discussions of each of these roles are provided in other sections of this Guide. The Core Documents section of this Guide provides detailed discussions of VV&A in each simulation category (new, legacy, federation) from the point of view of each of the five major roles (User, a Developer, M&S Program Manager, V&V Agent, and Accreditation Agent). Additional information on SMEs is presented in the special topic on *Subject Matter Experts and VV&A*. It is important for the success of VV&A that all of these players establish and maintain healthy working relationships.

Is there an "everyday" analogy to help to explain VV&A?

A Home Buying Analogy

There are many parallels between VV&A for simulations and the process of buying a house. Both start with requirements definition. In the case of a simulation, the requirements will usually be stated in a written document. In the case of a house, it may be a written description, or, it may be as simple as a discussion between the potential buyers and the real estate agent or builder.

Of course, in buying a house, one of the major decisions to make is whether to build a new house (p. 20) or buy one that is already built or in the process of being built (p. 20). In most instances, this decision is made based on economics and time – building a new home is generally more expensive, involves a number of additional factors,[15] and takes a lot more time. However, building may be the only way for the house buyers to satisfy all their requirements. Similarly, building a new simulation is an expensive, time-consuming project but it may be the only way for the User to be able to satisfy the requirements of the application. (See Building a Custom-Designed House (p. 20) for the analogy to simulation development.)

When the prospective home owners decides not to build, then they begin to look for a house that is already built, or in the process of being built, that meets their needs. (See Buying not Building (p. 23) for the analogy to legacy simulation.)

Building a Custom-Designed House

When the decision is made to build a new house, the buyers meet with the builder or architect to discuss the requirements and other criteria for the house design. No matter what form the requirements take, it is important for the builder (general contractor) to ***verify*** that his understanding of these stated or written requirements is an accurate reflection of what the buyers intended. This includes such basic steps as making sure that requirements are clearly stated and are not inconsistent. The buyers need to **verify**

[15] Locating and purchasing an appropriate lot, selecting a house plan, locating an architect and builder, financing, refining the requirements to cover all aspects of the house (e.g., selecting fixtures, appliances, windows and doors, flooring, landscaping, siding, rooflines, colors), etc.

that the requirements are correct, consistent and complete as given – that what the requirements say *is* what they really want, and that there are no important oversights or omissions. Otherwise, mistakes are bound to happen.

The tables below show some of the parallels between the artifacts and roles in a simulation development project as compared to a house construction project.

Comparison of Simulation and House Construction	
Simulation Artifact	**House Construction Artifact**
Requirements	• buyer's list of wants
Conceptual Model	• artist sketch, floor plan, interior sketches
Design Documents	• blueprints
Simulation	• house
Simulation Role	**House Construction Role**
User	• buyer
M&S PM	• general contractor (builder)
Developer	• subcontractors
V&V Agent	• specialty inspectors (electrical, plumbing)
Accreditation Agent	• chief building inspector

Just as a simulation developer will prepare a **conceptual model** for the simulation's logical structure and behavior, work on a house will often start with a floor plan layout, an artist's rendering of the exterior, and perhaps some interior sketches. These are, in effect, the conceptual model for the house; they allow the potential buyers to imagine what activities might take place in the house, and where their furnishings might be positioned, so they can cross-check the functional aspects of the house design against their original criteria. By this process the buyers confirm that the structure of the house is suitable for their needs in light of their expectations for the house. In essence, by completing this mental review, and reaching a conclusion that the house design (to the extent it is defined) is acceptable for their needs, they have ***validated*** the conceptual model of the house.

It is important to recognize that a simulation developer ***always*** works from a conceptual model. Even if it is not formally written down, it will still exist in the developer's mind. If it is not present at the beginning of development work, it must necessarily emerge in the developer's mind as the design is being prepared or the code is being written – else there would be no logical basis for organizing the software being produced. Just as it would be risky for someone to build a house without ever having seen a diagram of the floor layout, developing any significant simulation without a formal conceptual model can greatly increase the chance that the house will not meet the buyers' requirements (operational risk). Validating the conceptual model for the simulation means ensuring that its elements are sufficient to satisfy the requirements and, as necessary, are consistent with the environment and the systems being simulated.

Of course (unlike the log cabins once built on the American frontier), no one will proceed to construct a modern house from an artist's rendering. Some form of **design document**, usually a set of blueprints, is prepared to allow the house to be defined with sufficient precision for materials to be ordered and construction to begin. The blueprints will show numerous design details, such as plumbing fixtures and electrical outlets, that do not actually appear on the floor plan diagram, but are nevertheless assumed to be present in the finished house. A blueprint should provide enough information for a construction crew to assemble the house, but will not necessarily show every component in the house. For example, the plumbing pipe runs and the heating ducts will often be shown, but the exact pathway of the electrical wiring between the switches and outlets will usually not be shown, that being left to the electrician on the scene, at a later time.

Numerous checks of the blueprints are made by a number of people. The buyers will compare it to the floor plan to be sure that everything they expected is present. The builder will double check that the materials indicated, and the dimensions and clearances, are compliant with the state and local building codes. The plumbers, electricians, etc. check the blueprints to looking for problems in their areas of specialized expertise. In these ways the ***design*** is ***verified***. Similarly, verification of the software design, whether performed by specialists involved with the simulation development or outside specialists, ensures that it provides a suitable basis to proceed to the coding and implementation phase

At different stages of the construction of the house, inspections by **county building inspectors** serve to verify that the house is being built as intended with regard to factors the county may be concerned with, and the **chief inspector** will be checking to ensure that what is being built is generally consistent with the plans that had been filed with the county when the building permit was issued. These inspectors effectively serve in the role of the **subject matter experts** (SMEs) in simulation verification. The builder will also serve as an SME to the extent that he reviews the work of his subcontractors to make sure it has been done right. And of course, the buyers themselves may spot some discrepancies that all of the above may have missed, but for the most part they will tend to address their reviews to the features of specific interest to them.

> Example:
>
> Unless the buyers have a background in construction or in electrical work, they are not likely to spot code violation problems or safety hazards in the wiring unless the problems are blatantly obvious. They might not even attempt to inspect the wiring. On the other hand, while a building inspector might check the quality of the stone work (e.g., fireproof) for the fireplace, only the buyers, or perhaps the builder, will evaluate the aesthetics of the overall appearance of the stone work (e.g., color, pattern, size).

The different inspectors, while in one sense serving as SMEs, also serve as V&V Agents and Accreditation Agents, and their reviews of the work in progress correspond to ***implementation verification***. The extent and frequency of these inspections will depend on the importance of what is being inspected, on the degree of concern that some particular element might be more likely to cause problems (i.e., the level of risk), and whether problems had been detected at earlier stages of construction. These same types of factors will similarly influence the work of the V&V Agents for a simulation under development.

Once the house is built, there is general a series of final inspections and a walk-through to ensure the house has been built to both the buyers desires and to code. These for the house are like the ***results validation*** for a simulation. If the house is different from what was expected or county code violations are detected, then the buyers will complain and try to get the builder to make corrections or adjustments or, as a last result, refuse to pay. If simulation results are not as expected, if the simulation does not fit the user's needs, then corrections must be made there as well or the simulation will not be used. When the buyers accept the house and release funds to the builder, they are ***accrediting*** the house as satisfactory (i.e., fit for the intended purpose).

With houses, it is well understood why one cannot simply delay, until the final walkthrough, all of the various inspections and reviews that amount to performing V&V. If flaws are not spotted relatively quickly during construction, they may disappear under the cover of subsequent work. Even if flaws remain visible, if may not be possible to correct them without undoing and redoing later work, which can substantially raise the cost of correcting the problem. Sometimes the corrective work becomes cost-prohibitive, and the buyer is left with the unpleasant choice of either living with the problem or canceling the contract for the house.

Buying Not Building

The other option is to look for a house that is either under construction or was previously owned (i.e., houses built to someone else's specifications) that seems to fit all or most of their requirements. While this option avoids a lot of the complications involved in building, the tradeoff is that it is very unlikely that they will find any house that exactly fits their expectations since each has been built to someone else's. For that reason, the prospective homeowners need to carefully define and prioritize their requirements.

> Requirements: A three-bedroom, three-bath house with a two-door garage, office space, central air, ground floor with wheel-chair access, close to a good school and shopping center, maximum cost $180,000.

Each potential house is toured and inspected to see which of the requirements are addressed. In most situations, the buyers have to go on what they see and are told about a house, although in some instances house plans, heating bills, etc. are available for inspection and experts (e.g., plumber, electrician) can be brought in to inspect potential problems. Deficiencies are identified and analysis done to determine what it would take to make each house fit the homebuyer's needs.

Candidate houses can be separated into three groups based on how much time, effort, and cost is involved in satisfying the homebuyer's requirements:

- **As-is:** A house that meets all the high priority requirements and needs only cosmetic changes.

> A house that meets most of the buyers' needs "as-is":
>
> The house has three bedrooms and 2 ½ baths, a two-car garage, central air, wheel-chair access to all but one room on ground floor, in a good school district, with an extra bedroom in the basement that can be easily converted to an office, costing $180,000.
>
> Deficiencies: needs new carpets, repainting, addition of business phone line in the office, resizing of door on main floor for wheel chair access (no structural problems anticipated).

If the buyers select this house, then little needs to be done beyond having the inspectors brought in to ensure the house passes inspection. There are no major players beyond the buyers, house owner and the inspectors. Similarly, a simulation that can be used "as is," normally does not require the involvement of an M&S PM or Developer.

- **Minor modification (minor mod):** A house that meets most of the high priority requirements but needs some relatively simple, inexpensive alterations

> A house that meets the buyers' needs with minor modifications:
>
> The house has three bedrooms and 3½ baths, a two-car garage, central air, office space in a partially finished basement, partial wheel chair access, in a good school district, with an extra bedroom in the basement that can be easily converted to an office, costing $140,000.
>
> Deficiencies: Creating an office by finishing the basement. The conversion involves finishing the drywall on walls, painting, and adding carpeting. A wheel chair ramp to the front door is needed and the ground floor bath needs to have handicap sink and stool installed.

If the buyers select this house, then some work needs to be done before it can address all their needs; however, each problem can be addressed separately by a remodeler or specialty contractor, with little impact on the rest of the house. No general contractor would be needed to coordinate the renovations. However, additional inspections would be needed to ensure the house and the renovations are satisfactory. Similarly, a simulation that requires minor modifications normally does not require the involvement of an M&S PM. A Developer is needed to modify the code, but this may actually be done in-house and not by a separate organization.

- **Major modification (major mod):** A house that meets many of the high priority requirements but needs more elaborate and costly alterations; in the extreme, a fixer-upper.

> Major modification to meet the buyers' requirement for office space:
>
> The house has three bedrooms and 3 baths, a two-car garage, central air, wheel chair access, in a good school district, with office space in an unfinished loft over the garage, costing $130,000.
>
> Deficiencies: Creating an office by converting the loft above the garage. The conversion would require reinforcing the floor, adding internal walls, extending heating and plumbing lines, installing a half-bath, adding power and phone lines, insulation, and sound proofing, installing windows and a secure external entrance.

If the buyers select this house, then extensive work needs to be done before it can address all their needs. Because of the complexity of the renovation, a general contractor is needed to order materials, oversee the subcontractors, schedule the jobs, etc. Architectural plans of the garage would need to be examined and revised. A detailed design and specifications would need to be drawn up for the builders to work from. In addition, inspections, by the buyers, general contractor, and different specialists, would be done to at each stage of the renovation as well at the end to ensure the house and the renovations satisfy the buyers and conform to building codes. A simulation that requires major modifications normally requires an M&S PM and Developer and the V&V effort and accreditation assessment are much more intense.

A summary of the artifacts and roles involved in legacy simulation and house buying is given in the table below.

Comparison of Artifacts in Legacy Simulation and House Buying	
Simulation Artifact	**House Buying Artifact**
Requirements	Buyer's list of wants
Conceptual Model	Pictures, sketches, real estate property ads
Design Documents*****	Blueprints*****
Simulation	House
Legacy Simulation Role	**House Buying Role**
User	Buyer
Program Manager******	General Contractor******
Simulation Developer*****	Remodelers or Subcontractors*****
V&V Agent	Specialty Inspectors (Electrical, Plumbing,)
Accreditation Agent	Chief Building Inspector
*Not normally involved in "as is" option **Not normally involved in "as is" or minor modification options	

Analogy Conclusion

The situation for simulation development and use is not really all that different. There seems to be a frequent assumption that, because a line of code can always be changed with a text editor even at the 11th hour, with as little time and effort as when it was first put in place, that completed software still remains malleable, and that one can therefore wait until it is delivered to undertake the V&V. Certainly it is true that one can change a line of code far more easily than replacing a leaky pipe joint inside a wall, but in many other ways the analogy between house construction and software development is closer than may be apparent at first glance.

Code that is laid down early becomes a foundation on which later code relies, just like the foundation of a house. Code for implementing behavior that does not comply with recognized standards (e.g. networking protocols, file formats) will eventually have to be ripped out and modified just like plumbing that is not up to the standards of the county. If this is not done in a timely manner, then there will be a ripple effect on other parts of the software, causing code rework elsewhere, just as drywall work in a house must necessarily be damaged in order to repair a leaky pipe joint behind a wall.

Errors that are spotted at the software conceptual model or design document stage are often inexpensive to fix, but can be prohibitively costly after a lot of code has been written. Even changing only a small amount of code late in a project can be very expensive if it means that substantial software testing work needs to be redone. Early stage software design artifacts may not disappear quite like wiring behind drywall, but in a way they do, because (in most cases) the actual code becomes the only authoritative definition of the software as the work proceeds. With the exception of those still-fairly-rare-in-practice software projects where the code is actually generated from the design artifacts, their contents become increasingly obsolete and irrelevant as time marches on, and their usefulness for simulation maintenance gradually deteriorates.

If this aspect of the nature of software were more widely understood, it is doubtful that there would be such a widespread tendency to want to defer V&V until the end of simulation development. It is certainly tempting for those building a simulation or preparing it for use to want to "get on with the work", and to not be distracted by preparing for or conducting V&V tasks. Nevertheless, that is ultimately a penny-wise-but-pound-foolish approach. Because of a sound understanding of this phenomenon, V&V guidelines and directives have emphasized, again and again, that for simulation development and use to be successful, it is essential that V&V activities be integrated into the development and preparation process.

Summary - What are the costs and benefits of VV&A?

Because the objective of VV&A is to help ensure that credible simulations are used when making decisions (recognizing, again, that what is "credible" depends on the context), and because it would be illogical to try to make an important decision by using a simulation that is *not* credible, it could be stated that the primary results of VV&A go beyond providing merely a **benefit,** and reach the level of providing a **necessity**. Of course, things are rarely quite this simple or clear cut.

There is always some *a-priori* probability that a simulation, after a VV&A effort has been completed, will be shown to have been credible, all along. Therefore, there is always some temptation to want to skip VV&A for a simulation that one *expects* to be “credible” when all is said and done. This can easily lead to a “penny wise and pound foolish” strategy, and for a number of reasons this temptation should be avoided.

The first reason is that the inclusion of V&V in a well-established simulation development process can enhance the ongoing process at little, if any, cost. Many mature software development processes already incorporate steps that are very similar to verification as part of an established software quality assurance (QA) process. In simulations including a software QA effort, the V&V effort would consist of collecting the existing QA documentation, identifying any requirements that may not have been adequately addressed, conducting the V&V necessary to address them, and perform the results validation. The accreditation assessment would evaluate all the information from both the QA and V&V efforts regarding the simulation’s fitness for the specified purpose, and document the findings.

In cases where the software development process involved in the simulation does not already have a strong emphasis on quality, the addition of VV&A can actually *reduce* the overall *net* simulation development costs. The tasks performed in V&V, particularly verification, are effective additions to a software development process - they can help detect, and correct, software design errors at an earlier stage than might otherwise be the case. Given the substantial increase in the costs for correcting an error found late in a development process, early detection and correction can yield substantial cost savings in the areas of code testing and debugging. In fact, the cost savings in simulation development could help pay for the costs of the V&V effort.

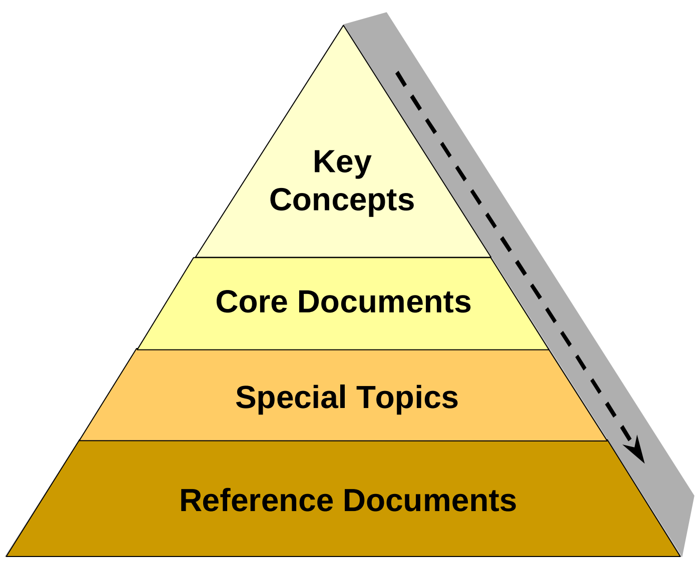
While the true costs of VV&A are not necessarily all that significant, the true benefits can be, because VV&A minimizes the risks and costs of making incorrect program decisions. These costs and benefits can, in principle, even exceed the costs of the program because they derive from the nature of the situations in which the results of the program are applied. Several examples of adverse effects due to inadequate system testing were given earlier in this document. Insufficient VV&A can lead to the same types of problems.

Because VV&A consists of a managed set of processes, there is no necessity for an up-front, all-or-nothing, go/no-go decision. Throughout the conduct of the VV&A processes, as evidence is being gathered, an *a-priori* assessment of the credibility of a simulation can be continually revised. At any point, the User might conclude that there is (or is not) sufficient evidence to make a credibility determination. Or, that the simulation is very *likely* to be proven credible, even if there is not yet complete certainty, and that the costs of further improving the degree of certainty are not warranted in comparison to the level of risk then remaining. In short, the VV&A effort can be managed so as to maximize the benefits relative to the costs.

VV&A does more than just ensure that models and simulations are credible – it helps avoid the costs of correcting development errors, and it helps prevent adverse impacts from incorrect program decisions. Overall, if conducted properly, the benefits of VV&A far outweigh the costs.

What's next?

This Recommended Practices Guide is intended to help a prospective user of VV&A to apply VV&A techniques correctly, efficiently, and in the appropriate circumstances. It is organized as a web-based document. The information provided in documents is arranged hierarchically by level of detail as depicted in the figure below. Each successive level includes documents that provide more detailed information on more focused topics of interest. Each document also includes numerous links to other RPG documents, allowing the reader to move easily though the topics of choice. All of the documents included in the RPG may be viewed using a web browser or downloaded as PDF files for printing.



The RPG Hierarchy

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The basic information about VV&A is presented in the ***Core Documents***. These are 15 different documents each tailored to discuss VV&A of a specific simulation category (new, legacy, federation) from the perspective of one of the five basic roles (user, M&S PM, developer, V&V Agent, Accreditation Agent). Information on specific topics can be found in the ***Special Topics*** and ***Reference Documents***. Additional reference material is provided in the form of a comprehensive bibliography, glossary, and acronym list. The ***Home page*** summarizes the other destinations available on the RPG web site.

References

DoD Instruction (DoDI) 5000.61: DoD Modeling and Simulation (M&S) Verification, Validation, Accreditation (VVA), April 1996 (currently under revision)

"Torpedoes of World War II," part of *The Silent Service* series of documentaries presented on The History Channel, A&E Television Networks, © 2000

External Links in This Document

"Mars Climate Orbiter Failure Board Releases Report", Release: 99-134, http://mars.sgi.com/msp98/news/mco991110.html

"Hubble Space Telescope Results in Planetary Science" (Introduction), Reta Beebe, Astronomy Department, New Mexico State University, Las Cruces, New Mexico, http://www.agu.org/revgeophys/beebe01/beebe01.html

RPG References in This Document

select menu: *RPG Diagrams*, select item: "VV&A and Federation Construction"

select menu: *RPG Diagrams*, select item: "VV&A and Legacy M&S Preparation"

select menu: *RPG Diagrams*, select item: "VV&A and New M&S Development"

select menu: *Reference Documents*, select item: "M&S Data Concepts and Terms"

select menu: *Special Topics*, select item: "Conceptual Model Development and Validation"

select menu: *Special Topics*, select item: "Data V&V for Federations"

select menu: *Special Topics*, select item: "Data V&V for Legacy Simulations"

select menu: *Special Topics*, select item: "Data V&V for New Simulations"

select menu: *Special Topics*, select item: "Problem Analysis"

select menu: *Special Topics*, select item: "Requirements"

select menu: *Special Topics*, select item: "Subject Matter Experts and VV&A"

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