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Guide for Generic Methodology for Verification and Validation (GM- VV) to Support Acceptance of Models, Simulations, and Data

GM-VV Volume 1: Introduction and Overview

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GM-VV Product Development
Group**

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Guide for Generic Methodology for Verification and Validation (GM-VV)
to Support Acceptance of Models, Simulations, and Data. Volume 1: Introduction and Overview

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1. Introduction

Model(s), Simulation(s), and associated data (hereinafter referred to collectively as “M&S”) are developed and employed as enabling technologies to support system analysis, design, test and evaluation, acquisition, training and instruction, and many more areas. Today, a wide variety of M&S are in use across an even wider range of different application and problem domains. M&S is usually applied when certain user needs cannot be achieved (e.g., risks, availability) with the actual system or otherwise are achieved more efficiently (e.g., costs, effectiveness) than with the actual system. However, in essence, all M&S provide some sort of abstract representation of systems (e.g., entity, phenomenon, process) that are based on different types of approximation. As such, M&S capabilities cannot fully replace the actual system and, more importantly, their usage introduces uncertainties. In combination with the increasing complexity of M&S being developed and employed, risks for failures, wrong usage, and misinterpretation of results are increasingly difficult to judge. Therefore, the benefits of using M&S always come at some cost, i.e., use risks. The key question then for M&S stakeholders (e.g., user, sponsor, developer, the public at large) is to determine which M&S asset is acceptable for a particular intended use, and which is not. Verification and Validation (V&V) are the processes that are typically used to support M&S stakeholders to determine and assure that an M&S asset is acceptable for the intended use. Hence, V&V provides information to be used in an acceptance decision process by M&S stakeholders, and associated practices such as M&S accreditation or certification¹.

1.1 Purpose of the GM-VV

The choice of which V&V method works best in a given situation depends on the individual needs and constraints of an M&S organization, project, application domain or technology. Moreover, V&V usually requires a complex mixture of various activities, methods, tools, techniques and application domain knowledge, which are often tightly coupled with the M&S development process. Therefore, many different approaches to V&V exist that rely on a wide variety of different V&V terms, concepts, products, processes, tools or techniques. In many cases, the resulting proliferation restricts or even works against the transition of V&V results from one M&S organization, project, and technology or application domain to another. Furthermore, history shows that V&V is often more of an afterthought than a built-in part of an M&S development, employment and procurement policy.

The purpose of the Generic Methodology for V&V (GM-VV) is to address these issues by means of providing general applicable guidance for V&V that:

- Facilitates common understanding and communication of V&V within the M&S community.
- Is applicable to any phase of the M&S lifecycle (e.g., development, employment, and reuse).
- Is M&S stakeholders' acceptance decision-making process oriented.
- Is driven by the M&S stakeholders' needs and M&S use risks tolerances.
- Is scalable to fit any M&S scope, budget, resources and use-risks thresholds.
- Is applicable to a wide variety of M&S technologies and application domains.
- Will result in traceable, reproducible and transparent evidence-based acceptance arguments.
- Can be instantiated on enterprise, project or technical levels alike.
- Facilitates reuse and interoperability of V&V outcomes, tools and techniques.

GM-VV is not aimed to replace the existing V&V approaches, methodologies, standards or policies of M&S organizations, technology and application domains; nor is GM-VV's intent to substitute common enterprise or project management practices prevalent within M&S client or supplier organizations. In addition, GM-VV is not intended to be prescriptive, in that it does not specify a single concrete or unique

¹ In this document the term acceptance is the decision to use a model, simulation, and the associated data for a specific purpose. Note: in the United States the term accreditation is the official certification that a model, simulation and the associated data are acceptable for use for a specific purpose. Note: in other communities certification is the process of providing a written statement that a (M&S) system is acceptable for operational use. For the purposes of this document these three terms are equivalent.

solution for all V&V applications. Rather, the GM-VV should be tailored to meet the needs of individual V&V applications.

1.2 Scope of the GM-VV

The GM-VV provides a technical framework that focuses on M&S V&V practices. Though interrelated, acceptance decision processes and associated practices such as M&S accreditation and certification are outside the scope of the methodology. GM-VV attains its generic quality from a technical framework that consists of three subparts: the conceptual, implementation and tailoring framework (Figure 1). This framework is rooted in established international standards and other related practices. The conceptual framework provides the terminology, concepts and principles to facilitate communication and a common understanding and execution of V&V within an M&S context. The implementation framework translates these concepts and principles into a set of generic building blocks to develop consistent V&V solutions for an individual M&S organization, project, and technology or application domain. GM-VV provides a tailoring framework that utilizes these building blocks to develop and cost-efficiently apply such V&V application instances. As such, the GM-VV provides a high-level framework for developing concrete V&V solutions and conducting V&V, into which lower-level practices (e.g., tools, techniques, tasks, acceptability criteria, documentation templates) native to each individual M&S organization, project, technology or application domain can easily be integrated.

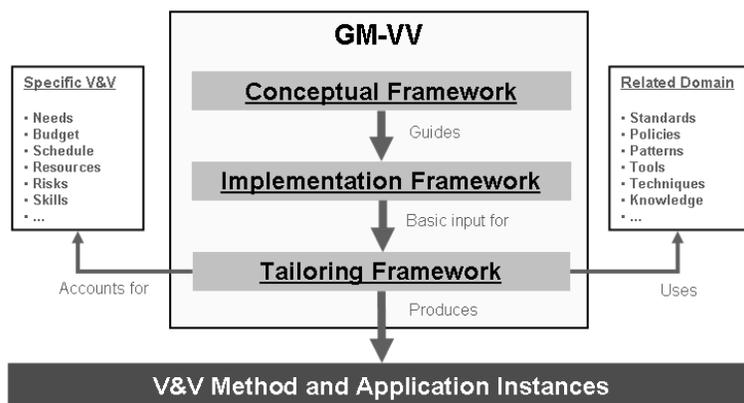


Figure 1 GM-VV Technical Framework Design and Operational Use Concept

1.3 Objective of the Document

The GM-VV is presented in three interrelated documents. The objective of this document is to provide an introduction to and overview of the GM-VV frameworks depicted in Figure 1. Therefore, this document only gives a high-level description of these frameworks that is sufficient to get started using GM-VV for V&V applications within M&S organizations or projects.

More details on the implementation framework components, as well as detailed guidance on how to apply these components in conjunction with the tailoring framework to develop concrete V&V solutions, can be found in the “GM-VV Volume 2: Implementation Guide (DRAFT)”. More technical and referential background information on the GM-VV, V&V in general and other related topics can be found in the “GM-VV Volume 3: Reference Manual (DRAFT)”.

1.4 Intended Audience of the Document

This document is intended for all M&S professionals, managers and users/sponsors, who are trying to gain knowledge about the importance and benefits of incorporating V&V within their organization or projects, and seeking a general applicable and standardized V&V methodology. This document is highly recommended for newcomers to the topic of V&V of M&S that want to learn and understand the basic

V&V terminology, concepts and application principles before immersing themselves in the specific details of V&V applications.

1.5 Acknowledgements

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2. References

The following references are helpful for the understanding of this document.

2.1 SISO References

Document Number	Title
SISO-GUIDE-001.2-XXXX-DRAFT	GM-VV Volume 2: Implementation Guide
SISO-REF-039-XXXX-DRAFT	GM-VV Volume 3: Reference Manual

2.2 Other References

Document Number	Title
IEEE Std 100-2000	The Authoritative Dictionary of IEEE Standards Terms, Seventh Edition, Current Version February 2007
IEEE Std 15288-2008 Second edition 2008-02-01	Systems and software engineering – System lifecycle processes
IEEE Std 1730™-2010 (Revision of IEEE Std 1516.3™-2003)	IEEE Recommended Practice for Distributed Simulation Engineering and Execution Process (DSEEP)
IEEE Std 1516.3™-2003 (superseded)	IEEE Recommended Practice for High Level Architecture (HLA) Federation Development and Execution Process (FEDEP)
IEEE Std 1516.4™-2007	IEEE Recommended Practice for Verification, Validation, and Accreditation of a Federation—An Overlay to the High Level Architecture Federation Development and Execution Process

3. Definitions

The table below lists the terminology used within the context of this methodology. Multiple definitions are provided where tailoring of the generic methodology is required to conform to organizational constraints. For terms not mentioned here, this document utilizes the standard definition as defined by IEEE 100 Dictionary of Standard Terms [IEEE Std 100-2000].

Acceptance: The process that ascertains whether an M&S system is fit for intended use [GM-VV].

Accreditation: The official certification that a model or simulation and its associated data are acceptable for use for a specific purpose. [B19].

Acceptability criteria: A set of criteria that a particular simulation, model or data has to be met to be acceptable for its intended use [GM-VV]. The criteria that the model, simulation, or federation of models and simulations needs to meet to be acceptable for its intended use [IEEE Std 1516.4TM-2007]

Conceptual model: A statement of the content and internal representations that are the user's and developer's combined concept of the model. It includes logic and algorithms and explicitly recognizes assumptions and limitations [B13].

Correctness: The extent to which an M&S system implementation conforms to its specifications and is free of design and development errors [GM-VV].

Fidelity: The degree to which a model or simulation reproduces the state and behavior of a real world object or the perception of a real world object, feature, condition, or chosen standard in a measurable or perceivable manner; a measure of the realism of a model or simulation; faithfulness. Fidelity should generally be described with respect to the measures, standards or perceptions used in assessing or stating it [B5].

M&S system: A combination of interacting M&S elements organized to provide a representation of the simuland for an intended use. Examples of M&S elements are simulation hard- and software, models, data, simulation applications, human operators and procedures [GM-VV].

Referent: A codified body of knowledge about a thing being simulated [IEEE Std 1516.4TM-2007].

Role: The specific set of responsibilities, obligations, and capabilities that are needed to perform an activity [GM-VV].

Simuland: The system being simulated by a simulation [B20].

Tailoring: The modification of V&V processes, V&V organization and V&V products to fit agreed risks, resources, and implementation constraints [GM-VV].

Utility: The property of an M&S system's application usefulness [GM-VV].

Validation: The process of providing evidence justifying the M&S system's validity [GM-VV]. Confirmation, through the provision of objective evidence that the requirements for a specific intended use or application have been fulfilled [IEEE Std 15288-2008]. The process of determining the degree to which a model or simulation and its associated data are an accurate representation of the real world from the perspective of the intended uses of the model. [B19]. The process of determining the degree to which a model, simulation, or data is an accurate representation of the real world, from the perspective of the intended purpose of the model, simulation or data [B17].

Validity: The property of an M&S system's representation of the simuland to correspond sufficiently enough with the referent for the intended use [GM-VV]. The property of a model, simulation or federation

of models and simulations representations being complete and correct enough for the intended use [IEEE Std 1516.4™-2007].

Verification: The process of providing evidence justifying the M&S system's correctness [GM-VV]. Confirmation, through the provision of objective evidence that specified requirements have been fulfilled [IEEE Std 15288-2008]. The process of determining that a model or simulation implementation and its associated data accurately represent the developer's conceptual description and specifications. [B19]. The process of determining the degree that a model, simulation, or data accurately represent its conceptual description and its specifications [B17].

4. Acronyms and Abbreviations

DoD	Department of Defense
DSEEP	Distributed Simulation Engineering and Execution Process
FEDEP	Federation Development and Execution Process
GM-VV	Generic Methodology for Verification and Validation
IEEE	Institute of Electrical and Electronics Engineers
IV&V	Independent Verification and Validation
M&S	Modeling and Simulation
NATO	North Atlantic Treaty Organization
NMSG	NATO Modelling and Simulation Group
REVVA	Referent for VV&A
SME	Subject Matter Expert
V&V	Verification and Validation
VV&A	Verification, Validation, and Accreditation

5. GM-VV Conceptual Framework

This chapter discusses the GM-VV conceptual framework. This framework provides fundamental and general applicable terminology, semantics, concepts and principles for V&V. The purpose of the framework is to facilitate communication, understanding and implementation of V&V across and between different M&S contexts (e.g., organizations, application domains, standards, technologies). The framework is the foundation upon which the GM-VV implementation framework rests (Chapter 6).

5.1 Links to Systems Engineering

Within the GM-VV, M&S systems are considered to be systems of systems that have a lifecycle and are subject to system engineering practices. Moreover, models and simulations are considered to be part of a larger system in which they are used (Section 5.2). From this perspective, M&S is a systems engineering specialization. V&V is an intrinsic part of the systems engineering process [B9], [B13], [B14], [B15]. Therefore, the GM-VV considers the V&V of M&S as a specialization of systems engineering V&V. Hence, the GM-VV can be integrated with, complement or extend the V&V processes within such existing systems engineering methodologies or standards.

5.2 M&S-Based Problem Solving Approach

The basic premise of the GM-VV is that models and simulations are always developed and employed to fulfill the specific needs of their end users (e.g., trainers, analysts, decision makers). Modeling and simulation is thus considered to be a problem solving process that transforms a simple statement of an end user's need into an M&S-based solution for the problem implied in the need. The GM-VV assumes that V&V always takes place within such larger context. This context is abstracted by means of defining four interrelated worlds (Figure 2). Together, these four worlds define a generic lifecycle and process view of M&S-based problem solving. A view that serves as a common basis, in which V&V for M&S (e.g., concepts, principles, processes, products, techniques) can be understood, developed or applied.

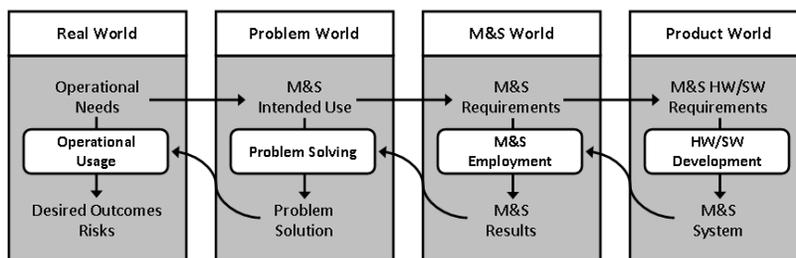


Figure 2 Four Worlds View of M&S Based Problem Solving

In the four worlds view of M&S-based problem solving, Real World operational needs are translated into an M&S intended use statement in the Problem World. In the M&S World this M&S intended use serves as the basis from which the M&S requirements are set for an M&S System. The M&S system is developed within the Product World, which involves setting low-level requirements for each element in the M&S system. M&S employment in the M&S World comprises well-controlled operation of the M&S system. The M&S results that come from the M&S system operation (i.e., simulation execution) are used in the problem solving process within the problem world. Finally, the M&S-based solution (e.g., new product, trained person, and analysis report) is transferred to the real world where it is exploited in the operational environment. When this M&S problem solving process is properly executed, the resulting solution should satisfy the originally identified needs with a minimal level of (use) risk in the Real World.

The M&S system, M&S requirements, M&S results and other development artifacts (e.g., conceptual model, software design, code) are thus always directed toward contributing to and satisfying the Real World operational needs. The degree of success of such M&S in satisfying these needs depends on how well they are specified, designed, developed, integrated, tested, used, and supported. These M&S activities require the contribution of individuals or organizations that have a vested interest in the success

of the M&S asset, either directly or indirectly. An individual or organization with such interest is referred to in GM-VV as a stakeholder. Stakeholders can play one or more roles in each of the four worlds such as M&S user/sponsor, supplier, project manager, software developer, operator, customer or subject matter expert (SME). Depending upon their role, stakeholders may hold different responsibilities in the M&S lifecycle processes, activities or tasks.

NOTE: The four-world view is not intended to be prescriptive or to replace alternative, more detailed M&S lifecycle and process implementations (e.g., FEDEP [IEEE Std 1516.3™-2003], DSEEP [IEEE Std 1730™-2010]) that are required or used by organizations. Such concrete implementations can be considered as tailored instances of this abstract four world view (Chapter 6).

5.3 V&V Problem Solving Approach

Within the four world context, stakeholders exist who are responsible for making acceptance decisions on the use of M&S (Section 5.2). Within the GM-VV, these stakeholders are referred as V&V User/Sponsor. In this context the V&V User/Sponsor could be an M&S User/Sponsor, Accreditation Authority or any other domain specific role that uses the outcomes of the V&V. V&V Users/Sponsors face the problem of having to make a judgment on the development and suitability of the M&S system or results for an intended use. The key issue here is that it is not possible to demonstrate with absolute certainty that the M&S system or results will meet the Real World needs prior to its actual use. Consequently, there is always a probability that the M&S-based solution is not successful when used (i.e., fails). Such a failure would result in an undesirable impact (i.e., a risk) on the operational environment. Therefore, an M&S system or result is only acceptable to the V&V User/Sponsor if he or she has sufficient confidence that the use of an M&S system or result satisfies the Real World needs without posing unacceptable risks (e.g., costs, liabilities). This M&S acceptability is something relative to different V&V Users/Sponsors: what is acceptable to one V&V User/Sponsor may not be acceptable for another. The V&V User/Sponsor's decision-making process therefore requires appropriate evidence-based arguments to justify his or her acceptance decision.

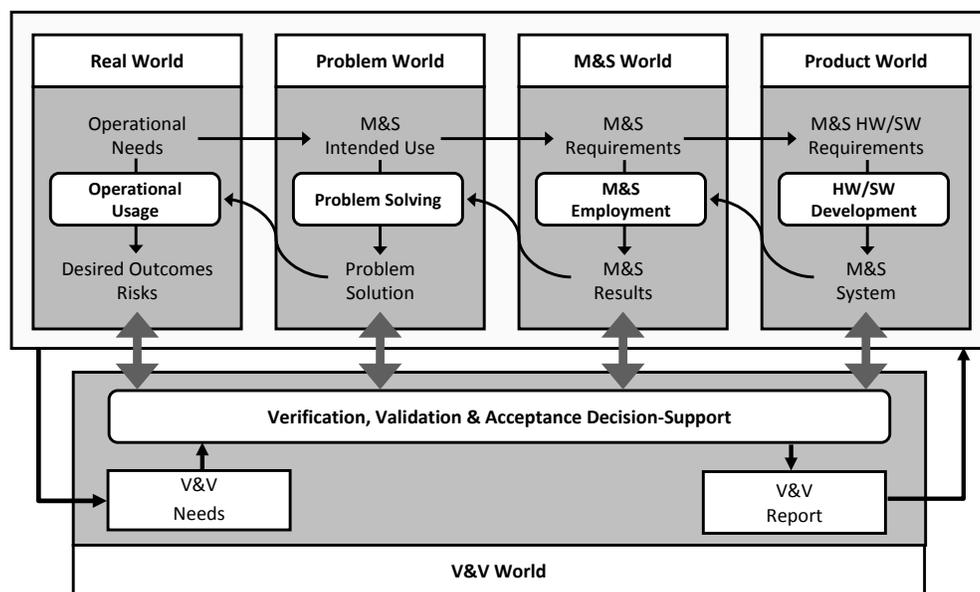


Figure 3 V&V World and Four World Interfacing

The basic premise of GM-VV is that V&V are performed to collect, generate, maintain and reason with a body of evidence in support of the V&V Users/Sponsors acceptance decision-making process. Here, validation is referred to as the process that establishes the V&V User/Sponsor's confidence as to whether or not they have built or procured the right M&S system or result for the intended use (i.e., M&S validity).

In other words "Did we build the right M&S system?" To ensure that the M&S system or results at delivery can be demonstrated to be valid, it is necessary to ensure that the M&S system is built and employed in the right manner. Here verification is referred to as the process of establishing V&V User/Sponsors confidence in whether the evolving M&S system or result is built right (i.e., M&S correctness). In other words "Did we build the M&S system right?". The GM-VV considers V&V as a specific problem domain of M&S with its own needs, objectives and issues. This domain is referred to as the V&V World (Figure 3).

The V&V world groups the products, processes and organizational aspects that are needed to develop an acceptance recommendation that can be used by the V&V User/Sponsor in his or her acceptance decision procedure(s). This recommendation included in a V&V report is the key deliverable of a V&V effort and contains evidence-based arguments regarding the acceptability of an M&S system or results. Here the GM-VV premise is that the acceptance decision itself is always the responsibility of the V&V User/Sponsor and decision procedure(s) may involve trade-off aspects beyond the V&V effort scope.

The development of an acceptance recommendation in the V&V world is driven by the V&V needs that are traceable to the V&V User/Sponsor's acceptance decision or procedure(s) needs (e.g., budget, responsibilities, risks, liabilities). Therefore, the extent, rigor and timeframe of a V&V effort depend on these needs. Depending on these needs, the V&V effort could span the whole or specific M&S lifecycle phase of the four worlds; could focus on one specific or multiple (intermediate) M&S products; and should match the development paradigm that was used (e.g., waterfall, spiral). Each case may require a separate acceptance recommendation with its own scope and development timeline. Moreover, the way the V&V effort interacts with the four M&S-based problem worlds also varies from case to case. These mutual dependencies are depicted in Figure 3 with bidirectional arrows that interface the V&V world with each of the four M&S-based problem solving worlds. Two classical types of V&V that can be identified based on the time frame of their execution are [B9], [B10], [B11], [B12]:

- Post-hoc V&V: V&V conducted in retrospect on an M&S system after development or on M&S results after M&S system employment.
- Concurrent V&V: V&V conducted in prospective throughout the whole M&S lifecycle to manage and improve the quality of newly developed M&S systems or results.

The GM-VV supports both V&V time frames but is not limited to these distinct types. A V&V effort can be post-hoc, concurrent, iterative, recursive or even be a recurrent effort in the case where legacy M&S products are updated or reused for a different intended-use.

5.4 Acceptance Recommendation, Acceptability Criteria and Evidential Quality

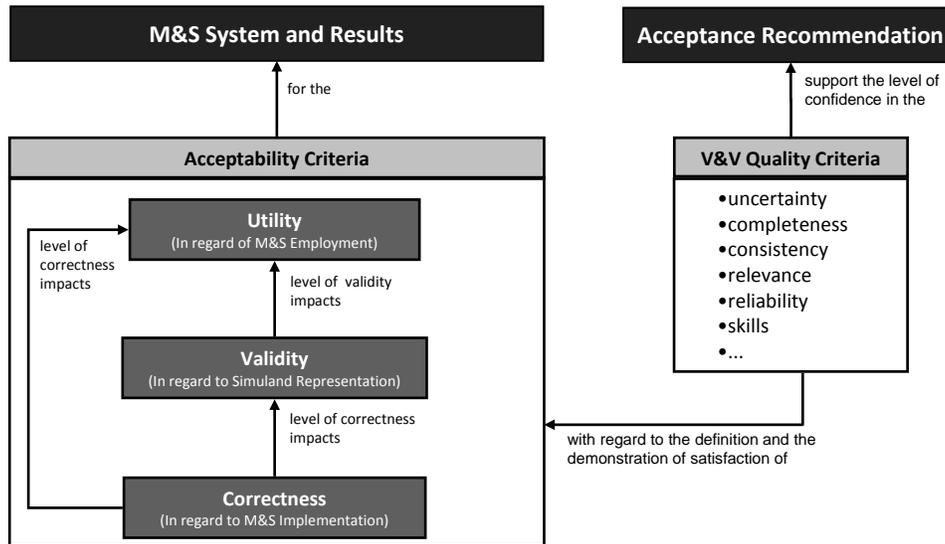


Figure 4 Utility, Validity, Correctness and V&V Quality Criteria Relationships

The objective of a V&V effort is to develop evidence upon which an acceptance recommendation is based (Section 5.3). This V&V objective is articulated as an acceptance goal. This high-level goal should be translated into a set of concrete and assessable acceptability criteria for the M&S system or result(s). Relevant and convincing evidence should then be collected or generated to assess the satisfaction of these criteria. When it is convincingly demonstrated to what extent the M&S system or result(s) does or does not satisfy all these acceptability criteria, a claim can be made on whether or not the M&S system or result(s) is acceptable for its intended use (i.e., acceptance claim).

The GM-VV identifies three types of M&S properties for which acceptability criteria could be set (Figure 4):

- **Utility:** this property refers to the extent to which the M&S system or result(s) is useful in solving the M&S user/sponsors needs. Utility properties could comprise sub-types such as M&S value (e.g., measures of effectiveness, measures of performance), cost (e.g., money, time) and use risks (e.g., impact, ramifications).
- **Validity:** this property refers to the extent to which the M&S system's representation corresponds to the simulated simuland (i.e., system of interest) from the perspective of the intended use. The level of validity impacts the utility.
- **Correctness:** this property refers to the extent to which the M&S system implementation conforms to its specifications (e.g., conceptual model, design specification); and is free of design and development defects (e.g., semantic errors, syntactic errors, numerical errors, user errors). The level of correctness impacts both validity and utility.

These three types of M&S properties include but not limited to capability, accuracy, usability and fidelity [B5], [B6]. To make an acceptance decision, the V&V User/Sponsor needs to know whether the M&S system or results are (un)acceptable, as well as the evidential value of this acceptance claim (i.e., strength). The required evidential strength to establish sufficient trust in such a claim depends on the use risks and the V&V User/Sponsor responsibilities (i.e., liability). The convincing force that can be placed on such a claim depends on the quality of the whole V&V effort. For this purpose, the GM-VV identifies quality properties that can be associated with identifying and defining the acceptability criteria; and developing convincing evidence for demonstrating their satisfaction (Figure 4).

- **V&V Quality:** this property refers to how well the V&V effort is performed (e.g., rigor) with regard to developing the acceptability criteria, collecting evidence, and assessing to what extent the M&S satisfy the acceptability criteria (e.g., evidential value, strength).

Typical examples of V&V quality properties are the completeness, correctness, consistency, unambiguous and relevance of the acceptability criteria or their supporting items of evidence. In the process of collecting or generating evidence, quality properties could comprise independence of applied V&V techniques or persons (section 5.7), knowledge gaps and uncertainties of referent data for the simuland [B8], skill level of V&V personnel, and reliability and repeatability of V&V techniques. Relevance and warrants for any assumption made in a V&V effort could also be addressed in the form of quality properties.

The defined acceptability criteria, the collected evidence and assessment of the satisfaction of these criteria are the basis for developing the arguments underlying the acceptance claim. This acceptance claim provides the V&V User/Sponsor with a recommendation regarding the acceptability of the M&S system or result for the intended use. In practice, an acceptance recommendation is not necessarily just a yes or no claim, in the sense that an M&S system or results can be accepted only if it meets all of the acceptability criteria and cannot be accepted if it does not. Meeting all the acceptability criteria means the claim can be made that the M&S system or result should be accepted to support the intended use without limitations. In case not all acceptability criteria are met, alternative weaker acceptance claims with underlying arguments can be constructed. Such alternative acceptance claims could, for example, provide recommendations regarding conditions or restrictions under which the M&S system or result can still be used (i.e., limit the domain of use); or on modifications that, when implemented, will lead to an unconditionally acceptable M&S system or results for the intended use. Another rationale for alternative acceptance claims is when convincing or sufficient evidence is lacking (e.g., access to data prohibited, or referent system unavailable for testing). In any case, an acceptance recommendation always requires well structured supporting arguments and evidence for the V&V User/Sponsor to make the right acceptance decision (Section 5.5). Depending on the identified M&S use risk, the V&V User/Sponsor can also decide not to take any actions when not all acceptability criteria are met by the M&S system. In that case, the V&V User/Sponsor simply accepts the risks associated with the M&S system use.

5.5 V&V Argumentation Approach: Structured Reasoning with Arguments

Developing an acceptance recommendation that meets the V&V User/Sponsor needs usually involves the identification and definition of many interdependent acceptability criteria, particularly for large-scale and complex M&S systems or for M&S-based solutions used in safety-critical, real-world environments. Demonstrating the satisfaction of acceptability criteria requires evidence. Collecting the appropriate evidence is not always simple and straight-forward, or even not always possible due to various practical constraints (e.g., safety, security, costs, schedule). In many cases, the collected evidence comprises a large set of individual items or pieces of evidence that may be provided in different forms or formats, and may originate from various sources (e.g., historical, experimental data, SME opinion). Moreover, the strength of each item of evidence may vary and the total set of collected evidence may even contain contradicting items of evidence (i.e., counter evidence). The quality of this effort determines the value of an acceptance recommendation for the V&V User/Sponsor (Section 5.4). Therefore, the arguments underlying an acceptance recommendation should be developed in a structured manner using a format where the reasoning is traceable, reproducible and explicit. Alternative approaches to implement such reasoning exist and may be incorporated within the GM-VV technical framework to tailor it the specific needs of an M&S organization or domain (Chapter 7). An example of such an approach is the V&V goal-claim network approach (Figure 5) as developed by the WEAG REVVA consortium and the NATO NSMG-073 task group [B17]. A V&V goal-claim network is an information and argumentation structure rooted in both goal-oriented requirements engineering and claim-argument-evidence safety engineering principles [B1], [B2], [B3], [B4].

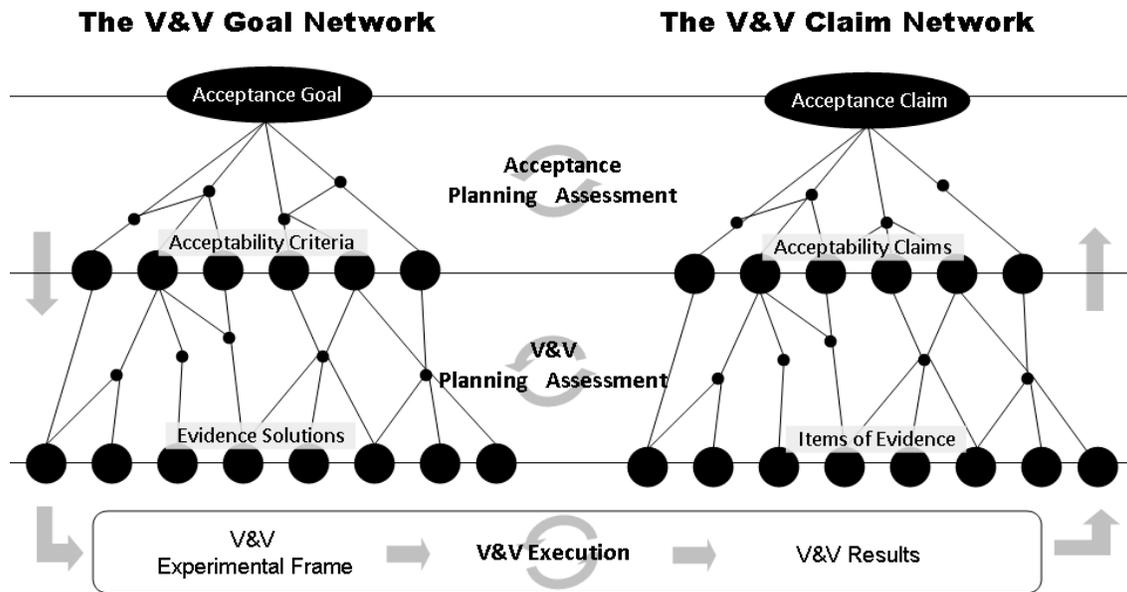


Figure 5 V&V Goal – Claim Network

Figure 5 provides an abstract illustration of a V&V goal-claim network. The left part of the goal-claim network is used to derive the acceptability criteria (section 5.4) from the acceptance goal; and deriving solutions for collecting evidence to demonstrate that the M&S asset satisfies these criteria as indicated by the top-down arrows (Figure 5). The acceptance goal reflects the V&V needs and scope (e.g., simuland, intended use). Evidence solutions include the specification of tests/experiments, referent for the simuland (e.g., expected results, observed real data), methods for comparing and evaluating the test/experimental results against the referent. Collectively, they specify the design of the V&V experimental frame used to assess the M&S system and its results. When implemented, the experimental frame produces the actual V&V results. After a quality assessment (e.g., for errors, reliability, strength), these results can be used as the items of evidence in the right part of the goal-claim network. These items of evidence support the arguments that underpin the acceptability claims. An acceptability claim states whether a related acceptability criterion has been met or not. Acceptability claims provide the arguments for assessing whether or to what extent the M&S system and its results are acceptable for the intended use. This assessment, as indicated by the bottom-up arrows (Figure 5), results in an acceptance claim inside the V&V goal-claim network. As such a V&V goal-claim network encapsulates, structures and consolidates all underlying evidence and argumentation necessary for developing an appropriate and defensible acceptance recommendation. The circular arrows in Figure 5 represent the iterative nature of developing a V&V goal-claim network during planning, execution and assessment phases of a V&V effort.

5.6 V&V Organizational and Management Approach

In order to facilitate efficient and high quality V&V, the V&V effort inside the V&V world should be executed in a controlled and organized way. The basic premise of the GM-VV is that the acceptance recommendation for an M&S asset is developed and delivered by means of a managed project. Moreover, GM-VV assumes that V&V is conducted by a person, a team of people or a dedicated organization with assigned responsibilities, obligations and functions. Therefore, GM-VV identifies three organizational levels at which V&V efforts can be considered. In order of the lowest to the highest organizational level these levels are:

- a) Technical Level: concerns the engineering aspects of a V&V effort (Sections 5.4 and 5.5) that are necessary to develop and deliver an acceptance recommendation,
- b) Project Level: concerns the managerial aspects related to the proper execution of the technical actions of a V&V effort,

- c) Enterprise Level: concerns the strategic and enabling aspects to establish, direct and support the execution or business environment for V&V efforts.

The core GM-VV concept on the V&V project level is the concept of a managed project. A V&V project can be viewed as a unique process comprised of coordinated and controlled activities that address: V&V effort planning in terms like cost, timescales and milestones; measuring and checking progress against this planning; and selecting and taking corrective actions when needed. A V&V project could be a separate project alongside the M&S project of which the M&S asset is part, or be an integral part of this M&S project itself (e.g., subproject, work package). A separate V&V project is particularly relevant in the case when a level of independence must be established between the M&S development and V&V team/organization (Section 5.7). On the V&V project level, GM-VV also provides derived concepts such as a V&V plan and report to manage the technical V&V work.

The core GM-VV concept on the V&V enterprise level is the concept of an enterprise entity. A V&V enterprise entity can be viewed as an organization that: establishes the processes and lifecycle models to be used by V&V projects; initiates or defers V&V projects; provides resources required (e.g., financial, human, equipment); retains reusable knowledge and information from current V&V projects; and leverages such knowledge and information from previous V&V projects. The V&V enterprise provides the environment in which V&V projects are conducted. GM-VV defines two types of enterprise entities:

- V&V Client: the person or organization that acquires V&V products or services,
- V&V Supplier: the person or organization that develops and delivers V&V products or services.

A V&V agreement is arranged between a V&V client and V&V supplier to provide products and/or services that meet the V&V client's needs. Both these V&V entities could be organizations (e.g., companies) separate from the organization that develops or acquires M&S or it could be different units (e.g., department, division, group) within a single M&S supplier or client organization. Typically, a separate V&V supplier is an organization that has the provision of independent V&V products and services to external V&V clients as its core business (Section 5.7). Though depending on their business model, an M&S supplier or client organization could have their own V&V supplier entity that may provide V&V services and products to internal and external V&V clients alike.

NOTE: The GM-VV implementation framework is primarily focused on the V&V supplier entity.

5.7 V&V Levels of Independence: Acceptance, Certification and Accreditation

An independent V&V (IV&V) authority is often described as an organization or a person that is employed to conduct V&V, independent of the developer's team or organization [B9], [B10], [B12]. The need for IV&V is mostly driven by:

- risks and liabilities taken by the V&V User/Sponsor's acceptance decision
- level of trust the V&V User/Sponsor has in the M&S developer
- authoritative policies and regulations that may demand independent V&V for the M&S intended use
- lack of specialist skills, tools and techniques by user, sponsor or developer to perform V&V

In this context, the terms "certification" and "accreditation" are often used. Certification is the process of providing a written guarantee that a (M&S) system is acceptable for operational use [IEEE Std 100-2000]. Accreditation has two connotations. Accreditation is the official certification that a (M&S) system is acceptable for use for a specific purpose, as used by the US DoD [B9]. This meaning of the term of accreditation is the one that is part of the commonly used acronym, VV&A, which stands for verification, validation and accreditation. This acronym has a specific meaning within the US DoD M&S and decision maker community, since it integrates V&V effort within their formal acceptance decision process.

In practice however, it is highly incumbent upon the V&V User/Sponsor acceptance decision needs and complexity of the M&S system as to which parts and to what extent V&V should be conducted in an independent manner. Therefore, the GM-VV adopts a sliding scale of independence for V&V [B8], which can be selected accordingly to match the V&V needs. The justification and selection of a proper level of independence is supported within GM-VV through the use of the V&V argumentation network (section 5.5). Within this sliding scale for independent V&V, certification and accreditation can be located in the right part of the scale (Figure 6).

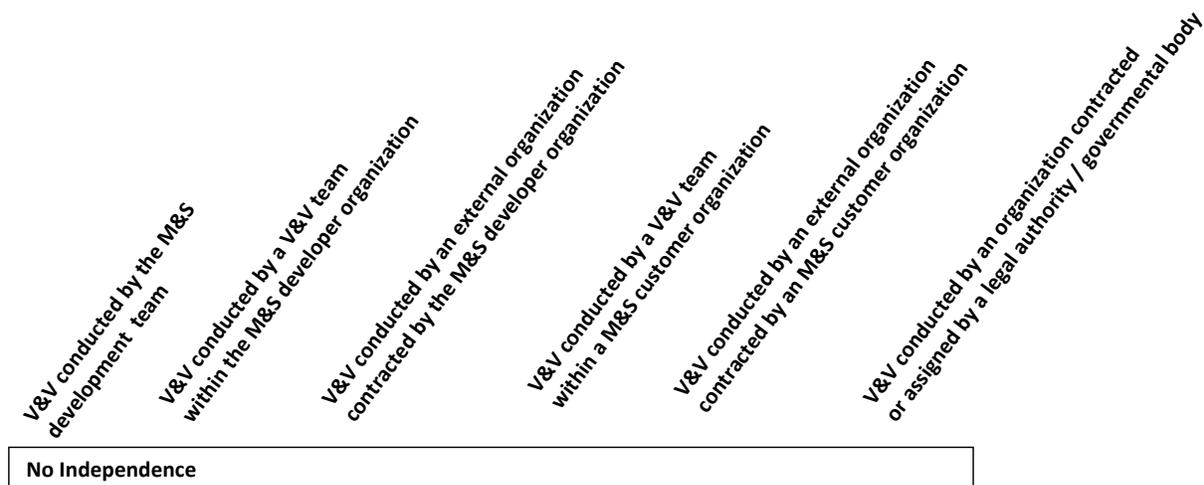


Figure 6 Levels of Independent V&V

5.8 V&V Information and Knowledge Management

V&V of M&S is an information and knowledge intensive effort. In particular, during the V&V of large scale, distributed or complex M&S applications, care must be taken to preserve or reuse information and knowledge. Therefore, GM-VV applies the memory concept on both the V&V project and enterprise levels (Section 5.6). A memory is viewed as a combination of an information and knowledge repository and a community of practice [B7]. The repository is a physical place where information, knowledge objects, and artifacts are stored. The community of practice is composed of the people who interact with those objects to learn, understand context and make decisions.

The V&V project memory provides the means to manage information and knowledge produced and used during the life-time of an individual V&V project. V&V is often an iterative and recurrent process linked to an M&S system's lifecycle, hence V&V products for an M&S system may have different configurations. Therefore, a V&V project memory may also retain records on possible different V&V product configurations. The V&V enterprise memory retains the total body of information and knowledge from past and current V&V projects to sustain and support the cost-effective execution of future V&V projects. Such reusable information could be, for example, M&S technology or domain specific recommended practices, acceptability criteria, V&V goal-claim network design patterns, V&V tools and techniques, or policies and standards. On a more strategic level, a V&V enterprise memory could retain information and knowledge on V&V project costs and maturity as well.

6. GM-VV Implementation Framework

The GM-VV implementation framework translates the GM-VV basic concepts of Chapter 5 into a set of generic V&V building blocks (i.e., components). These may be used to develop a tailored V&V solution that fits the V&V needs of any particular M&S organization, project, application, and technology or problem domain. The implementation framework has three interrelated dimensions: product, process and organization (Figure 7). The underlying principle of this framework is that the V&V needs of the V&V User/Sponsor in the M&S four-world view are addressed by one or more V&V products, those being the

V&V report and possibly other custom V&V products the V&V User/Sponsor may need. These V&V products in general require intermediate products (i.e., information artifacts) and associated processes to produce them. The V&V processes are executed by a corresponding V&V organization that is responsible for the development and delivery of the V&V products. In general the V&V effort should result in a V&V report to be delivered to the customer containing one or more of the information artifacts. Individual needs will drive which V&V products are required.

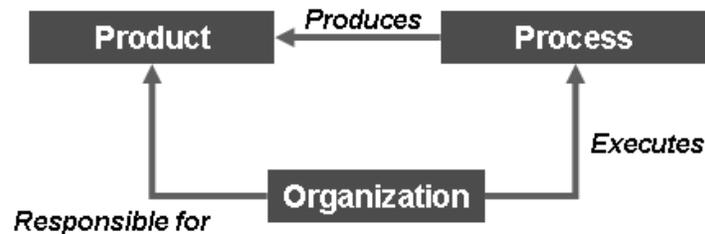


Figure 7 GM-VV Implementation Framework Dimensions

As indicated in Figure 7, the GM-VV implementation framework consists of three key dimensions:

- **Products:** the information artifacts that may be delivered, developed or used throughout a V&V effort. These artifacts can have multiple instances, representational and documentation formats. Examples of such tailored documentation formats are the US DoD accreditation plan and report templates, and the V&V plan and report templates [B18].
- **Processes:** the set of activities and tasks that comprise V&V execution as well as those management tasks that increase the efficiency and effectiveness of the V&V effort. These activities and tasks are inspired by the IEEE standard system lifecycle processes model [IEEE Std 15288-2008] and can be carried out recursively, concurrently, and iteratively.
- **Organization:** the roles played either by people or by organizations in the V&V effort. The roles are defined in terms of responsibilities and obligations. Depending on the M&S organization, project and application domain needs; several roles could be played by separate organizations, separate people in one organization or by a single person.

The V&V effort culminates in a V&V report that is comprised of the information generated throughout the execution of the V&V and acceptance decision-support process (Figure 3). The following sub-sections provide an overview of the information artifacts, activities and roles that are implemented or produced during this execution. They are ordered according to the GM-VV technical, project and enterprise levels. In this volume only high level descriptions are provided. Detailed descriptions of all components can be found in Volume 2 [SISO-GUIDE-001.2-XXXX-DRAFT].

It is important to re-emphasize the tailorable nature of the methodology. GM-VV provides all the elementary information artifacts, activities, tasks and roles to address the most common technical, project and enterprise level aspects of a V&V effort. Depending on the M&S project and organizational needs one could choose not to implement all GM-VV components or one could choose to adjust them accordingly. This is particularly relevant for M&S organizations that already have some project and enterprise level components in place, and only require technical level V&V (intermediate) products, processes and roles to conduct their V&V effort. The overall tailoring and application concepts of the GM-VV implementation framework are provided in Chapter 7.

6.1 Technical level GM-VV information artifacts, activities and roles

This subsection describes the technical activities performed, the artifacts produced and the roles that are filled during the execution of the V&V effort. These lists are not all inclusive and may be tailored to reflect the needs and constraints of a specific V&V project.

Technical level Information artifacts:

- V&V Requirements; requirements placed on the V&V project deliverables and execution, including constraints. Note these are not the M&S requirements for the M&S system.
- V&V Context Information; M&S information needed prior to or during the V&V project. It captures information regarding the M&S problem solving lifecycle and process such as the M&S system requirements, intended use and risks (Figure 2).
- V&V Plan; specifies the V&V execution process, tasks and experimental frame to be implemented as well as the associated resources.
- V&V Experimental Frame; a set of experiments, tests and conditions used to observe and experiment with the M&S system to obtain V&V results.
- V&V Results; the collection of data items produced by applying a V&V experimental frame to an M&S system.
- V&V Argumentation Structure; captures the derivation of acceptability criteria from the acceptance goal, and the derivation of the V&V experimental frame specification from the acceptability criteria. It provides the rationale for these derivations. It integrates the V&V results into items of evidence, and provides argumentation for the acceptability claims underlying the acceptance recommendation. (Possible implementations could be a V&V goal-claim network (Section 5.5) or a traceability matrix [IEEE Std 1516.4™-2007], [B10]).
- Acceptance Recommendation; an account or record containing the recommendations on the acceptability of the M&S system for the intended use. This acceptance recommendation integrates descriptions of all the information artifacts.
- V&V Report; accumulates and documents the information generated throughout the V&V effort, along with information on how the V&V effort has been performed.

Technical level processes

- V&V Requirements Definition; defines the V&V requirements and the associated V&V context information for the V&V project based on the V&V User/Sponsor needs.
- Acceptance Planning; transforms the V&V requirements and context information into associated acceptability criteria for the M&S system.
- V&V Planning; transforms the acceptability criteria into the V&V Experimental Frame specification and the V&V plan.
- V&V Execution; implements and executes the V&V Experimental Frame according to the V&V plan to produce V&V Results; integrates them into items of evidence for the M&S system. This process can include the following activities [B16]:
 - Verify M&S requirements
 - Collect, analyze and apply relevant M&S system historical information
 - Verify and validate the conceptual model
 - Perform verification on the M&S system design and/or implementation
 - Verify and validate the data and knowledge sets
 - Validate the M&S results
- V&V Assessment and Integration; assesses and integrates the items of evidence into acceptability claims regarding whether or not the M&S system satisfies the acceptability criteria.
- Acceptance Assessment and Integration; assesses and integrates the acceptability claims into claims regarding to what extent the M&S system is acceptable for the intended use (i.e., acceptance recommendations).
- V&V Product Delivery; packaging the information artifacts into the V&V Report and delivering it to the V&V User/Sponsor, and archiving the information artifacts in appropriate repositories.

Technical level roles

- Acceptance Leader; responsible for specifying the acceptability criteria, assessing the acceptability claims and constructing the acceptance recommendations.

- V&V Leader; responsible for developing the V&V plan, assessing and integrating the V&V results into items of evidence, and constructing the acceptability claims.
- V&V Implementer; responsible for implementing the V&V experimental frame and generating V&V results. Examples of V&V implementers are SMEs, M&S developers and test engineers.

6.2 Project level GM-VV information artifacts, activities and roles

This subsection describes the managerial activities performed at project level, the artifacts produced and the accompanying organizational structure. The project level provides a supporting environment that can enhance the effectiveness and efficiency of the technical V&V work. This includes a V&V project memory that facilitates the management and maintenance of the total body of V&V information artifacts produced during a V&V project. These lists are not all inclusive and may be tailored to reflect the needs and constraints of a specific V&V project.

Project level information artifacts

- V&V Project Plan; a coherent arrangement of activities and tasks to guide both the V&V project execution and control. Can incorporate or reference the technical level V&V plan.
- V&V Project Status Report; an account or record to provide information on the conduct of the V&V project, its status and issues.

Project level processes

- Project Planning; produces, maintains and communicates an effective V&V project plan.
- Project Assessment and Control; reports on the V&V project status and supports V&V project plan execution to ensure that the schedule, costs, deliverables and objectives specified in a V&V agreement are met.
- Decision Management; provides information to determine the most beneficial course of action for the V&V project where alternatives exist.
- Risk Management; provides information to identify, analyze, monitor and manage V&V project risks continuously.
- Configuration Management; defines the mechanism to establish and maintain the integrity of all project deliverables, associated intermediate products, and information during the V&V project execution.
- Information Management; supports appropriate information exchange among all parties and roles involved in the V&V project execution.
- Measurement; collects, analyzes, and reports data related to the overall V&V project, its performance and the quality of its deliverables.

Project level role

- V&V Project Manager; responsible for managing the V&V project to assure that the V&V report and possibly other custom V&V product(s) are developed and delivered according to the V&V agreement.

6.3 Enterprise level GM-VV information artifacts, activities and roles

This subsection describes the managerial activities performed at the enterprise level, the artifacts produced and the accompanying organizational structure. The enterprise level provides a supporting environment that can establish a V&V effort and can enhance its effectiveness and efficiency. This includes a V&V enterprise memory that facilitates the management and maintenance of the total body of V&V information artifacts, knowledge and products required to sustain the delivery of V&V products by a V&V supplier for any M&S project. These lists are not all inclusive and may be tailored to reflect the needs and constraints of a specific enterprise that executes V&V projects.

Enterprise level information artifacts

- V&V Agreement; a contract, statement of work or any type of agreement between a V&V client entity and a V&V supplier entity for the delivery of a V&V product(s).

Enterprise level processes

- Agreement Management; establishes and manages the V&V agreement between V&V client and the supplier entity.
- Life Cycle Model Management; defines, maintains and ensures availability of V&V lifecycle models suitable for carrying out any V&V project.
- Project Portfolio Management; initiates and sustains necessary, sufficient and suitable V&V projects in order to meet the strategic V&V supplier entity objectives.
- Resource Management; ensures that necessary resources are provided for carrying out V&V projects and that skills, competencies, and infrastructure are maintained, consistent with the enterprise entity needs.
- Quality Management; ensures that the delivered V&V product(s) meets the enterprise entity quality standards and achieves V&V User/Sponsor satisfaction.

Enterprise level roles

- V&V Enterprise Manager; responsible for managing the environment in which V&V projects are conducted. This role contributes to the arrangement of a V&V agreement from the supplier side.
- V&V User/Sponsor; responsible for specifying the V&V requirements and endorsing the delivered V&V product(s). This role contributes to the arrangement of a V&V agreement from the client side.

7. GM-VV Tailoring Framework

GM-VV recognizes that a particular M&S organization, project, application, technology or problem domain may not need all these components or use them directly as-is. Therefore, the GM-VV components are intended to be selected, combined and modified accordingly, to obtain an effective and efficient V&V effort of sufficient rigor. This is particularly relevant for M&S projects and organizations that already have some project and enterprise level components in place, and only require technical level V&V (intermediate) products, processes and roles to conduct their V&V effort.

The basic premise of the GM-VV tailoring concept is that the GM-VV should first be cast into a concrete V&V method fit for an organization or application domain, and secondly this instance should be optimized for a V&V project. This tailoring concept is implemented by means of a framework that refers to all three levels of the GM-VV implementation framework (Chapter 6). The objective of this GM-VV tailoring framework is to adapt each GM-VV (intermediate) product, process and role to satisfy the specific requirements and constraints of:

- An organization that is employing the GM-VV (*e.g., company policies, standards*)
- A domain in which the GM-VV is employed (*e.g., standards, regulations, technologies*)
- A V&V supplier entity delivering V&V products or services (*e.g., standards, processes*)
- A V&V project (*e.g., time, budget, scale, complexity, risk, resources*)

The GM-VV tailoring framework applies four basic tailoring approaches:

- Tailoring by Extension: adaptation of the implementation framework by adding custom V&V products, processes, activities, tasks and roles. For example, a V&V Client organization or application domain may require additional custom artifacts not foreseen by the GM-VV.

- **Tailoring by Reduction:** adaptation of the implementation framework by deleting products, processes, activities, tasks and roles due to constraints such as inaccessibility of data and information protected by intellectual property rights, security or technical restrictions.
- **Tailoring by Specialization:** adaptation of the implementation framework by adding or using domain specific V&V methods, techniques and data that are unique for a V&V project, organization or application.
- **Tailoring by balancing:** adaptation of the implementation framework by fitting a suitable cost-benefit-ratio towards an acceptance recommendation. The level of acceptable M&S use risk should drive the rigor and resources employed for V&V. Therefore, in this approach one tries to balance aspects such as:
 - M&S use-risk tolerances and thresholds
 - criticality and scope of the acceptance decision
 - scale and complexity of the M&S system
 - information security, withV&V project resource variables such as
 - time schedule
 - budget
 - V&V personnel skills
 - infrastructure.

Hence, balancing establishes the suitable and feasible level of rigor for the V&V effort.

Tailoring by these four approaches should be performed in accordance with the three dimension design principle of the GM-VV implementation framework (Figure 7), to obtain a consistent and coherent V&V method and project. For example, each new or specialized product needs a corresponding process (activities, tasks) and role (responsibilities, obligations).

Successful application of the tailoring framework results in a modified or new V&V method instance conforming to the GM-VV. This consists of concrete V&V organization, products and processes, which should achieve the V&V objectives of an M&S organization, project, technology or application domain.

8. Conclusion

This document provides a brief overview of the Generic Methodology for V&V. The GM-VV provides a conceptual and implementation framework to justify the acceptability of models, simulations, underlying data, and results for an intended use. The framework emphasizes the importance of V&V products and organization, and not only the V&V processes.

The GM-VV implementation framework has been designed as a common basis for developing alternative, tangible V&V methods that match the specific V&V needs of M&S organizations and projects. For this purpose, the GM-VV offers a tailoring framework accommodating any M&S organization and project need (e.g., budget, scale, complexity, risk tolerance, intended use). The GM-VV also provides a catalog of different terminologies and vocabularies. This catalog facilitates the common understanding of V&V approaches and demonstrates the GM-VV compatibility with existing V&V practices and standards.

This document is the first in a series of three volumes describing the GM-VV. The primary objective of this volume is to familiarize newcomers and introduce V&V practitioners to the main concepts, implementation and tailoring aspects of the GM-VV. The GM-VV should be applied as explained and detailed in GM-VV Volume 2: Implementation Guide (DRAFT) supported by GM-VV Volume 3: Reference Manual (DRAFT).

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