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

GM-VV Vol. 3:
Reference Manual

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1. Introduction

Models, Simulations, 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, M&S provides 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 comes 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 certification.

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

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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.
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 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 frameworks (Figure 1). This technical 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 components 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 generic components to develop cost-effective 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.

1.3 Objective of the Document

The GM-VV is presented in three interrelated documents. The objective of volume 1 [SISO-GUIDE-001.1-2012] is to provide an introduction and an overview of the GM-VV conceptual framework. The objective of volume 2 [SISO-GUIDE-001.2-2013] is to provide 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. This document [SISO-REF-039-2013] is a reference product that aims to document the foundations of the GM-VV concepts, their dependencies and rationale and to provide example applications of the methodology.
1.4 Intended Audience of the Document

This document is intended for all M&S professionals and M&S users/sponsors who want to apply the GM-VV at the technical, project or enterprise level. This document should be consulted whenever a deeper technical understanding of the methodology or its application is required.

1.5 Acknowledgements

This document was created as a community effort by the “Generic Methodology for Verification and Validation to Support Acceptance of Models, Simulations, and Data” Product Development Group (GM-VV PDG). This PDG was chartered by the Simulation Interoperability Standards Organization (SISO) Standards Activity Committee in 2007. A Technical Co-operation Agreement between the NATO Modeling and Simulation Group (NMSG) and SISO was established in 2007, which formalized the individual participation by NMSG members in SISO's Balloted Products Development and Support Process. This document would not have been possible without the support from the former European consortium REVVA (Referent for VV&A) and the follow-on NATO Modeling and Simulation Task Group MSG-073 supported by Canada, Denmark, France (lead nation), Germany, The Netherlands, Sweden, and Turkey. MSG-073 members played a significant role in the SISO GM-VV PDG activities.

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2 References

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

2.1 SISO References

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<tr>
<td>SISO-GUIDE-001.1-2012</td>
<td>GM-VV Vol. 1: Introduction &amp; Overview</td>
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2.2 Other References

[8] IEEE Std 1730, IEEE Recommended Practice for Distributed Simulation Engineering and Execution Process (DSEEP)
[10] IEEE Std 1278.4, IEEE Recommended Practice for Distributed Interactive Simulation - Verification, Validation, and Accreditation
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 [1].

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 [B2].

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 [5].

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 [B48].

Convincing Force: A statement that expresses how persuasive a piece of evidence is.

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 [B3].

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 [5].

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 [B1].

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 [3]. 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. [B2]. 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 [B1].
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 [5].

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 [3]. The process of determining that a model or simulation implementation and its associated data accurately represent the developer’s conceptual description and specifications [2]. The process of determining the degree that a model, simulation, or data accurately represent its conceptual description and its specifications [B1].

V&V client: The person or organization that acquires V&V products or services [GM-VV].

V&V supplier: The person or organization that develops and delivers V&V products or services [GM-VV].
## 4 Acronyms and Abbreviations

<table>
<thead>
<tr>
<th>AIF</th>
<th>Argumentation Interchange Format</th>
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<tr>
<td>AOCS</td>
<td>Air Operation Control Station</td>
</tr>
<tr>
<td>BVR</td>
<td>Beyond-Visual-Range</td>
</tr>
<tr>
<td>CAE</td>
<td>Claim Argument Evidence</td>
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<tr>
<td>CM</td>
<td>Conceptual Model</td>
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<tr>
<td>DG</td>
<td>Drafting Group</td>
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<tr>
<td>DIS</td>
<td>Distributed Interactive Simulation</td>
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<tr>
<td>DMO</td>
<td>Defence Materiel Organisation (NL, Australia)</td>
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<tr>
<td>DoD</td>
<td>Department of Defense (Australia)</td>
</tr>
<tr>
<td>DOE</td>
<td>Design of Experiments</td>
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<tr>
<td>GM-VV</td>
<td>Generic Methodology for Verification and Validation</td>
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<tr>
<td>GSN</td>
<td>Goal Structuring Notation</td>
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<tr>
<td>HWSH</td>
<td>Heavy Weather Ship-Handling</td>
</tr>
<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers</td>
</tr>
<tr>
<td>IoE</td>
<td>Items of Evidence</td>
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<tr>
<td>KMar</td>
<td>Royal Netherlands Marechaussee</td>
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<tr>
<td>M&amp;S</td>
<td>Modeling and Simulation</td>
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<tr>
<td>NATO</td>
<td>North Atlantic Treaty Organization</td>
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<tr>
<td>NMSG</td>
<td>NATO Modeling and Simulation Group</td>
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<tr>
<td>PDCA</td>
<td>Plan, Do, Check, Act Loop</td>
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<td>PDG</td>
<td>Product Development Group</td>
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<tr>
<td>POM</td>
<td>Public Order Management</td>
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<tr>
<td>RNLAF</td>
<td>Royal Netherlands Air-Force</td>
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<tr>
<td>SISO</td>
<td>Simulation Interoperability Standards Organization</td>
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<tr>
<td>SME</td>
<td>Subject Matter Expert</td>
</tr>
<tr>
<td>SoI</td>
<td>System-of-Interest</td>
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<tr>
<td>V&amp;V</td>
<td>Verification and Validation</td>
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5 Foundations

In this chapter the foundations of the GM-VV are discussed. The chapter starts with a discussion on systems engineering and how this can be applied to M&S. Next the V&V of M&S Systems is described. Conducting V&V of M&S in the most effective and efficient way involves making trade-off decisions, these are considered in the section on tailoring.

It must be noted that the background knowledge presented here is not a paraphrase of the material of the original sources. Some of the presented knowledge is an integrated interpretation, to better understand its utilization inside the GM-VV.

5.1 Systems engineering applied to M&S

This section briefly discusses systems engineering as applied to M&S. An M&S system is a specific type of a system, thus adhering to systems engineering principles. Such principles include hierarchical M&S systems thinking with systems observables and frames, and an M&S problem-solving approach with an M&S system life cycle.

5.1.1 What is a system

A system is generally considered as a set of interrelated components which interact with one another. These components interact in an organized manner towards a common purpose for the benefit of a user. The components of a system may be non-homogenous and may among other things consist of one or more of the following: hardware components, software components, humans, organizations, processes, documents, or naturally occurring entities.

5.1.2 Hierarchical description of a system

System components are defined to be the smallest parts of a system the user wants to consider in the context of its objectives. Systems can be very complex and may consist of many components. The commonly used approach to deal with this complexity is to organize the system into a hierarchical structure of subsystems [3] [B5] [B6][B38].

A subsystem is considered to be a subset of components of a larger system acting together to fulfill specific functionality. Using the given definition this means that a subsystem is a system itself. A subsystem may be further decomposed into subsystems as well. In this manner, a large and complex system becomes a hierarchically structured system that allows for development or analysis in a modular fashion [B7] [B8], see Figure 2. Through ‘ports’ [B7], the white ovals in Figure 2, information is exchanged with a system.

![Figure 2: Modular and Hierarchical Structured System View Example](image)

A hierarchically structured system can be viewed with various levels of openness. Typically three levels are defined: black-box, grey-box and white-box. In a black-box view the internal components and relations are either not (yet) known, can’t be accessed, or are left out of consideration because they are...
not needed by the user. In grey box view, subsystems are “partially” known, accessible or left out for consideration. Depending on how many and how deep the system is known, accessible or considered, allows for various shades of grey. If the hierarchical structure of a system is fully known up to the component level, it is referred to as the white-box view.

5.1.3 Observables, Observability, Controllability and Disturbance

System, sub-system and system components are studied or observed from the outside by means of what is commonly called observables. In systems engineering observables are associated to the concept of a port [B7]. A port is used for stimulating (input) or observing (output). Through such ports (white ovals in Figure 2) information is exchanged with a system. Sub-systems are also coupled and interact with each other by means of ports in order to produce the behavior of the parent (sub) system [B8].

The black, grey and white-box approach also relates to two other fundamental systems engineering concepts: controllability and observability [B31]. A system is controllable if any arbitrary point in the system internal behavioral space can be reached starting from another arbitrary point in this space by means of admissible or available input stimuli. Likewise, a system is observable if the full system internal behavioral space can be identified from the observed knowledge of the system input and output data. Within systems engineering, external stimuli exist that cannot be manipulated but can influence a system. These external stimuli coming from the system's environment are known as disturbances. Disturbances can be divided in two types, those which are directly observable and those only observable through their influence on the system output ports, see Figure 3.

5.1.4 Frames

In practice, a system under consideration, the SoI (System-of-Interest) is always used or analyzed within a certain operational context i.e., environment. This context provides input, causes disturbances and interprets the system output. The frame concept is used as the formalization of this context [B7] [B9]. In other words, a frame is a formal specification of the operational usage of a SoI to meet its target objectives. A frame is itself also a system and can therefore also be hierarchically decomposed into subsystems and finally coupled components (see Section 5.1.2).

A frame can specify one specific usage of a system, but it can also specify a whole family of uses, e.g., a series of experiments. Therefore, the frame itself has input ports through which frame input data can be entered to control the usage of the system. These frame inputs are used by the internal frame components to implement the way the system is stimulated with input data and how the output data is observed. These output data are mapped by the frame components into outcome measures that
characterize how well the objectives have been accomplished. These outcome measures are the frame system output. The observed system output and the outcome measures can also be utilized by the frame components for run-time assessment and feedback control.

5.1.5 The roles of humans
Humans are considered to be user/sponsor or components of a system. Humans as a system user/sponsor are the beneficiaries of the utilization and/or acquisition of the system that is intended to solve their problem.

As a system component, a human fulfills the role of an operator carrying out specified system services. Consequently, human component(s) contribute to the overall performance and characteristics of the systems of which they are a part.

5.1.6 What is systems engineering
Systems engineering can be described as "an interdisciplinary approach and means to enable the realization of successful systems." Systems engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems engineering considers both the business and the technical needs of all User/Sponsors with the goal of providing a quality product that meets the user needs [B38]. For more detailed information on systems engineering the reader is referred to [2] [3] [8] [B5] [B6] [B50] [B51].

5.1.7 System life cycle model and processes
A system life cycle is generally considered to be the evolution of a system starting from a needs statement for the system up to its disposal. In systems engineering that evolution is executed in several phases. Each phase typically needs specific techniques and results in an (intermediate) product. Although the precise definitions of the phases varies for different systems engineering approaches [2] [3] [B5] [B6] [B50], a general pattern can be discerned. Here the system life cycle is subdivided into five high-level phases that characterize the evolution of the system. In each of these a number of activities are executed while applying various systems engineering tools and techniques. Appropriately grouped together these activities are the system life cycle processes. In general such a process consists of several tightly coupled activities and is specified in terms of a specific goal, input and outcome products. The activities may each be further specified in a set of tasks. These activities are not necessarily sequential; they are often performed in parallel and in an iterative fashion. A variety of systems engineering processes have been proposed [2] [3] [8] [B5] [B6] [B50] [B51].

The following five live-cycle phases describe a typical systems engineering process:

- **Concept Phase**
  This stage is where an identified need is examined, requirements for potential solutions are defined, potential solutions are evaluated and a system specification is developed. The selected technical realization process determines which tasks are executed and which intermediate products are produced, but commonly the following tasks exist: user requirements definition, feasibility analysis, conceptual design specification and analysis.

- **Development Phase**
  in this phase the system concept is transformed into a complete and detailed system design. The selected technical realization process determines which tasks are executed and which intermediate products are produced, but commonly the following tasks exist: system (requirements) definition, preliminary design and detailed design, specification of production.

- **Production Phase**
  here the system is built according the design and specification of the production. This yields the construction of the system components, their integration and testing.
• **Operation Phase**
  this phase is entered once the system is completely deployed and accepted. During this phase the user's needs are fulfilled by operation the system for its intended use. Usually during this phase the system needs support and maintenance, which might include system modifications to fix errors or address new unforeseen issues in the operational use or to meet new user expectations. In these changes the system as a whole or one or more of its subsystems might be reused for other intended uses.

• **Retirement Phase**
  once it is demonstrated that the system is no longer useful or cannot compete with newly available alternatives, it enters its retirement phase. Here the system is phased out of actual operation and any existing knowledge and experience gained with the system has to be consolidated in an archive.

In the above list of phases a number of technical tasks are indicated which are necessary to create and operate the system. Collectively these are known as the technical realization process. Besides this technical realization process some other life cycle processes also need to be mentioned:

• **Acquisition and Agreement Process**
  The process typically starts with the identification of the need and intended use of a system in the operational context, followed by a feasibility study with identification of risk factors and cost/benefit estimates. Next, a contractual agreement is negotiated between a supplier and the User/Sponsor, who now becomes a client.

  Throughout the whole system life cycle, negotiation and communication between the client and supplier is continued to support the trade-off decision-making on the satisfaction of the client's needs by the system. This process is stopped once the system is formally approved by the User/Sponsor by signing off the contractual agreement.

• **Project Management Process**
  Once the project is granted, the supplier starts the project management process to manage the whole project such that the client's needs are met within budget and on time. This process comprises the classical tasks of project planning, assessment and control loops. During this process appropriate negotiation and communication moments (i.e., decisions gates) are held with the client.

• **Enterprise Management Process**
  This process establishes the environment in which the projects are conducted, their outcomes and performance capitalized, fused and analyzed for maturing and optimizing the system supplier's organization. This process has the aim to improve the supplier's business undertaking managing resources, assets, cost and risks in a competitive and/or uncertain business environment.

• **Evaluation Process**
  Throughout the whole system life cycle it has to be evaluated whether the system fulfills its intended use and the User/Sponsor needs are (still) met. The evaluation process works in parallel to and directly on the technical realization process. This process is classically associated to the area of verification and validation. Therefore, this evaluation process is the major entry and anchoring point for the application of GM-VV. The execution (when and how) of this process is driven by the agreement between client and supplier and has to be carefully managed in the project and enterprise management process.
5.1.8 What is M&S

In this section only the background needed for the foundations on V&V of M&S systems in Section 5.2 is provided, as applied within the GM-VV. For a more theoretical and complete description of Modeling and Simulation (M&S) the reader is referred to [B7] [B8] [B23].

Modeling and simulation are closely related to systems engineering as discussed in the previous section. A possible definition of a model is that it is an abstract representation or specification of a system. Abstraction in this context is a process in which a relative sparse set of relevant (sub)systems, relationships and their inherent qualities are extracted or separated from a more complex reality. A model can represent a system that exists in our material world but also non-existing or virtual systems or hybrid combinations thereof. That part of (the imagined) reality that the model is supposed to represent is called the simuland. Often models are described hierarchically as presented in Section 5.1.2 for systems, see also [B7].

![Diagram of real and imagined world, simuland, modeling, physical model, computational model](image)

**Figure 4**: That part of the real and imagined world that is being modeled is called the simuland. Image partly from [B58].

In a simulation the model is used to replicate the simuland behavior. Thus a simulation is a method, software framework or system to implement and evaluate a model over time i.e., it is a system in which a model is made to execute and is exercised. This model in its executable form is called the M&S system.

The M&S system is provided with input and its output is used within a certain context provided by a frame such as discussed in Section 5.1.4, the frame is now called the Simulation Frame. The model that is executed in the simulation is controlled and observed by means of its ports (see Section 5.1.3.). Through these ports simulation data, stimuli or settings are entered into the model and simulation output leaving the executed model is observed. During the simulation the model behaves according to a dynamics that represent the state change and behavioral properties of the simuland. The notion of time, behavioral representation and frame are fundamental characteristics of a simulation [B54].

To properly replicate the simuland for the intended use, the model is configured, controlled and stimulated by the Simulation Frame by means of input trajectories, scenario's, parameters, environment variable settings and experimental control settings. Furthermore, environment disturbances may impact the behavior of the M&S system (see Section 5.1.3). During the execution of the model, human input can become part of the displayed behavior. This can be from trainees, but also from operators such as opponent players to provide stimuli to the trainees or Subject Matter Experts (SMEs) that interfere with the execution of the simulation for some purpose dictated by the Simulation Frame (e.g., keeping the execution within a desired regime).
5.1.9 The M&S Problem Solving Approach

In the M&S literature different kinds of life cycle’s for M&S systems exist, which are usually tailored for a specific problem or application domain in which the M&S system is used [4] [5] [B10] [B21] [B22]. Moreover, there exist several ways these life cycles are traversed from simple single pass waterfall model to more complex ones such as spiral development paradigms. However, it is generally possible to map these life cycle models to the generic systems life cycle as presented in Section 5.1.7. This yields that systems engineering concepts and processes equally well hold for M&S systems.

In order to adapt the general systems life cycle concept to the M&S domain and to prepare it for the use in the GM-VV, it was necessary to slightly modify and expand the phases described in Section 5.1.7. The result is the four-worlds view on the M&S problem solving approach as presented in Figure 6.

The four worlds are:

- **Real World**
  The Real World is, as the name suggests, the actual real-life world of which we are part of. It is where the need for some solution arises and where the solution is applied to obtain the desired outcomes. It is also where the real operational and other business risks exist in case the M&S based problem solution is not fit for purpose. Stakeholders from this world may for example be commanders that need well trained soldiers or the general public that wishes to use buildings that are designed with safety in mind.
• **Problem World**
In the Problem World the needs of the Real World are further examined and solved. For some needs the problem may be training, in which case the Problem World is actually the “Training World”, or if the need involves analysis it is the “Analysis World”. Here the generic "Problem World" is used. The problem solution may consist of different parts, for example a training program may consist of class room training, simulator based training and live training; an analysis may consist of a literature study, simulation based analysis and SME interviews. In the Problem World the complete problem is solved. Thus the simulation based component (i.e., M&S results) may only be part of the solution.

Stakeholders from within the Problem World are those parties involved in the complete solution (e.g., organizations) such as schools and their teachers in case of training, analysts in case of an analysis problem. Stakeholders from the Real World or their Subject Matter Experts (SMEs) are typically also involved in the Problem World.

• **M&S World**
In the M&S World the focus is on the M&S based components of the Problem Solution. Here M&S (sub) systems are defined and used. It starts with the specified M&S intended use from the Problem World from which the requirements are derived such as the M&S System components that are needed, which scenarios are to be used and which personnel are needed. After the M&S System becomes available from the "Product World" the execution takes place and the M&S Results are constructed. Stakeholders from within the M&S World are trainers, trainees or other controllers that control the simulation. Other stakeholders may be white cell personnel including red-force players and analysts that examined the M&S execution.

• **Product World**
The Product World takes the M&S requirements from the M&S World and determines the M&S hardware and software requirements. The M&S System is constructed and delivered to the M&S World. Stakeholders within the Product World are those organizations that build and deliver the M&S System such as programmers, model developers, system or software architects and managers of repositories with reusable models.

In Section 5.1.7 five life cycle phases are mentioned. These can be mapped to the four worlds in Figure 6. In the Concept Phase the need is examined, requirements are defined and a concept is constructed. This takes place in the Real World and the Problem World. The modeling activity of M&S usually takes place in several stages: a conceptual model [B46][B47] is typically constructed in the Problem World and is subsequently made specific for simulation in the M&S World. In the Development Phase system and software requirements are defined and the design is made. The high level design of a model or simulation is typically constructed in the M&S World and given more detail in the Product World. The Production Phase of the systems life cycle can be mapped to the Product World in Figure 6. In the Operation Phase the system is used. For M&S this takes place in the M&S World where the M&S System is employed in order to obtain M&S Results. If an M&S System has produced all needed M&S Results and is no longer needed it is in the Retirement Phase, which is not explicitly mentioned in Figure 6.

### 5.2 Verification and Validation of M&S Systems

This section provides background information on Verification and Validation (V&V) of M&S Systems. V&V processes overlay the M&S problem-solving approach as presented in Section 5.1. The objective of the V&V process is to demonstrate with appropriate evidence that the M&S system and the M&S results fit the intended use and do not pose unacceptable real-world risks. Such information is needed to make well-informed and confident decisions throughout the whole M&S life cycle (Section 5.1.7).

#### 5.2.1 V&V of systems versus V&V of M&S systems

V&V is used to check the correctness of the M&S system as well as the usefulness of the M&S system in solving the Real World needs. As outlined in the previous chapter, GM-VV’s premise is that M&S is a specialization of general systems engineering practices. As a consequence the GM-VV considers V&V of M&S as a specialized standard V&V practices within systems engineering. To this extend, GM-VV defines
three properties that embody the key concepts that help to signify the difference and commonalities of V&V of M&S systems and that of general systems engineering. These V&V properties are utility, validity and correctness.

![Acceptability Criteria](image)

Figure 7: Systems engineering V&V (left) versus M&S V&V (right)

There is a difference between general systems engineering and systems engineering as applied to M&S. In M&S, abstractions of the simuland are used with the aim to replicate the simuland behavior (see Section 5.1.8). The additional work for V&V of M&S is to provide evidence to show that these abstractions produce behavior that replaces the simuland behavior to such an extent that the M&S system or its results fit its intended use (i.e., validity).

5.2.2 Uncertainty, Risks, Confidence, Credibility and Trustworthiness

In systems engineering the interim products resulting from the life cycle steps may be faulty for various reasons. This is true for general systems engineering, but even more so for M&S because of the modeling process. M&S is considered as being more an art than a science [B7] [B18] [B19] [B20] [B22] [B24]. Due to possible introduced errors from standard systems engineering, those from the modeling process and errors in the employment of the M&S System can lead to uncertainties about the utility of M&S. These uncertainties ultimately lead to risks in the Real World (Figure 6 below). The relevant concepts are briefly discussed as follows:

Uncertainty
Uncertainty is an inclusive term. It covers the lack of certainty, whether the uncertainty can be modeled probabilistically or not. This definition allows the term uncertainty to be applied to anything. Different communities restrict the application of this term to, for example, predictions of future events, physical measurements already made, and unknowns [6] [7] [B14]. Two major types of uncertainty can be defined: uncertainty due to the lack of knowledge (i.e., epistemic uncertainty) and uncertainty due to non-deterministic behavior (i.e., stochastic uncertainty). Seminal work in the field of uncertainty, also in the context of modeling and simulation is the work of SANDIA labs [B15] [B16] [B17].

Risk
Risk is a concept that denotes the probability of specific undesired eventualities. There are many definitions of risk that vary by specific application and situational context. However in general usage the convention is to focus only on potential, negative impact to some aspect of value that may arise from a future event. In engineering [B55] [B56], the definition of risk is a factor that could result in future negative consequences: usually expressed in terms of impact and likelihood or probability. Risk is thus a state of uncertainty where some possible occurrence of an event that results in a loss, catastrophe, or other undesirable outcome.
Confidence, Credibility, Trustworthiness

Confidence is generally described as the state of being certain, either that a hypothesis or prediction is correct, or that a chosen course of action is the best or most effective. Credibility in general refers to the trustworthiness of a source or a message. A survey on the terms credibility, confidence and trustworthiness show that they are often used interchangeably within the M&S domain [B18] [B26] [B27] [B28] [B29] [B30] [B35]. A clear example is Knepell’s definition for confidence assessment which is defined as the process of assessing the credibility of a model or simulation [B25].

All aforementioned definitions have several implications in common that complicate the objective assignment of any measure of credibility to a model or simulation [B18] [B26] [B27] [B28] [B29] [B30] [B35]. For the M&S domain credibility is nearly synonymous with confidence and trustworthiness. Credibility is a property of the information being presented that involves the belief of the observer or recipient of that information. Therefore, the perception of credibility is inherently subjective and cannot be meaningfully measured. Furthermore, credibility is only loosely coupled to the process for deriving the presented information. Therefore, the integrity of that process can only contribute to credibility if the observer understands that process and appreciates its limitations. Finally, in order for the observer to trust the credibility of the process for producing information they must also trust that the people who applied that process did so correctly.

Within the GM-VV the terms credibility, confidence and trustworthiness are also used interchangeably and considered to have the same semantics.

In the text below we will also use the term convincing force. The convincing force expresses how persuasive a piece of evidence is.

5.2.3 The V&V Problem Solving Approach

The inherent uncertainties in the quality of M&S systems and results (Section 5.1.8) introduce risks when such assets are used. The V&V effort should effectively and efficiently provide insight into and advice on the quality of the M&S system or results, and its associated use risks. Ultimately the V&V results are used in order to make good and defensible decisions on the use of M&S systems and results [B56].

In software engineering it is well known that the costs to fix errors increases for successive stages in the system's life cycle [B65][B66][B67][B69]. For M&S, which is largely composed of software, this situation is probably similar. Over the complete M&S life cycle (see Section 5.1.9) the V&V effort should lower the total cost of M&S development and employment, see Figure 8. The estimated cost resulting from the M&S use risk should outweigh the estimated costs of the V&V effort including the costs resulting from any remaining M&S use risk after doing V&V. A case study [B68] shows a high return on investment is possible. Based on the M&S use risk and the amount of risk the V&V User/Sponsor is willing to bear, the V&V needs can be determined. These needs state the extent and rigor of the V&V effort and restrictions (e.g., budget and time-frame for that effort).
The V&V effort can cover the whole M&S life cycle with an entry point at the evaluation process. For full flexibility however, the V&V effort needs its own life cycle that can, when needed, be implemented independently and in parts.

In order to efficiently execute the V&V effort, the V&V life cycle should match and be aligned with the M&S life cycle where possible. In this case V&V results in an early stage of the M&S life cycle can be used to improve the M&S System. This not only includes the original development but also changes later in the life cycle of the M&S System: updates, upgrades and new uses.

Several V&V processes exist that are developer oriented and closely follows a chosen M&S development process \[5\][10]. The GM-VV, however, is independent of any specific M&S development process. The GM-VV can be applied:

- concurrently with a development process or post-hoc,
- in an iterative and/or recursive way, and
- for updates, upgrades or re-use of the M&S system for a different purpose.

The V&V approach of GM-VV is based on the generic M&S problem solving approach as described in Section 5.1.9. The V&V approach is described in Section 5.3 of Volume 1 [SISO-GUIDE-001.1-2012], see Figure 9 below.

![Figure 9: The V&V World and Four World interfacing](image)

The GM-VV has been designed with full flexibility in mind and can be applied to each of the individual phases of the M&S life cycle. The V&V outcomes for these individual phases can later be combined to realize a complete concurrent V&V process of the whole M&S life cycle. In Section 5.2.4 it is described how a V&V argumentation concept can be constructed to support this approach.
Even though the V&V effort can be executed in parallel, sequentially or iteratively, the whole V&V effort must be managed and organized in support an effective and efficient result. The GM-VV management and organizational approach for V&V efforts is described in GM-VV Volume 2 [SISO-GUIDE-001.2-2013].

### 5.2.4 V&V Argumentation Approach

As described in Section 5.2.1 the V&V effort should provide information on Utility, Validity and Correctness of the use of the M&S system and if the results fit its intended use. Acceptability criteria must be set, tests defined and executed, and results interpreted to build an evidence-based argument for the Acceptance Recommendation.

The Acceptance Recommendation, which the V&V User/Sponsor uses in the M&S acceptance decision, should address the acceptability of the M&S System for its intended use. In order to be able to make the Acceptance Recommendation, a clear set of links must be available from the Real World needs to the claims on acceptability. The paths from the intended use to the acceptance recommendation should be transparent, reproducible and fully traceable. The GM-VV calls this the Argumentation Structure.

Various ways of instantiating this Argumentation Structure exist, such as traceability matrices [B52]. GM-VV recommends using concepts from assurance cases [B12] and advanced requirements engineering practices [B53]. This results in an implementation of the Argumentation Structure as the Goal-Claim Network (Figure 10).

The concept of assurance cases exist in the safety domain. For industry the development, review and acceptance of an assurance case forms a key element of their safety assurance processes. An assurance case can be defined as "a reasoned and compelling argument, supported by a body of evidence, that a system, service or organization will operate as intended for a defined application in a defined environment" [B59]. For the GM-VV the "as intended" statement equates to the Goal part of the Goal-Claim network, which ultimately indicates what evidence is needed. See Figure 22 for an example of what a Goal network can look like. Similarly, the "reasoned and compelling argument" statement equates to the Claim part of the Goal-Claim network, which ultimately must be supported by Items of Evidence. This provides a logical chain of reasoning by which an argument is established [B57].

A generic ontology for Argumentation Structures and tools is the Argumentation Interchange Format (AIF) [B32] [B33] [B34]. AIF has many instantiations including the Goal Structuring Notation (GSN) [B59] and the Claim Argument Evidence (CAE) [B61], which are two common methods used to describe assurance cases.

Building on the above mentioned works, the GM-VV proposes to construct the transparent, reproducible and fully traceable paths from the intended use to the acceptance recommendation in three parts:

- The V&V Goal Network, where acceptability criteria and evidence solutions are derived,
- Building and executing the V&V Experimental Frame in order to obtain the needed evidence, and
- The V&V Claim Network to construct claims based on the obtained evidence.

In Figure 10 the complete network as proposed by GM-VV is shown. The figure is an abstract representation of the Argumentation Structure, which is explained in Volume 1 [SISO-GUIDE-001.1-2012] in Section 5.5.
In the sections below we discuss the implementation of the V&V Goal-Claim Network using traceability matrices, the GSN and CAE. Finally we will discuss the V&V Experimental Frame and V&V techniques.

5.2.4.1 Mapping a Requirements Traceability Matrix to the Goal-Claim Network

The V&V Goal-Claim Network defines a framework that tracks the relationship of Items of Evidence back to an Acceptance Claim and associated Acceptance Goal. This construct can be translated into the more traditional Systems Engineering terminology of requirements, tests and test results (See Section 5.1). In both constructs, the ultimate objective is to be able to trace how the produced V&V evidence supports the acceptance decision.

A traceability matrix establishes the relationship between defined requirements (both high level and derived), acceptability criteria, test procedures, and test results. The traceability matrix provides insight into the completeness of the testing process relative to the defined requirements and identifies potential testing gaps. Figure 11 provides an example of a Traceability Matrix. This example establishes the mapping of each high level requirement (the second column) down to the test results (second to right-most column) for the implemented V&V tests. Working through the columns from left to right, the matrix documents:

A. A requirement number
B. A high level requirement (e.g., the simulation shall be able to represent airbases and landing zones)
C. A mid-level requirement (if needed)
D. The acceptability criteria associated with the requirement
E. A reference citation to the source document detailing how the derived requirements were defined
F. A derived requirement (e.g., location of base, shelter options for base, logistics, damage)
G. A reference citation to the source document for the implemented tests and associated results (e.g., test plan, test report)
H. A description of the V&V test that will address the associated requirement
I. A description of the V&V test procedures implemented
J. Documentation of the results of the implemented V&V test
K. Any notes related to the V&V test implantation and/or results

As can be seen in Figure 11, multiple derived requirements can be mapped to a high level requirement. While not specifically shown, multiple tests can be associated with a single derived requirement. It is
important to note that test results should not be accepted and recorded in the matrix without documented evidence (e.g., a test report) to substantiate the finding.

![Figure 11: Example of a V&V Traceability Matrix](image)

As each test procedure is implemented, the result is documented in a formal test report. The completed tests are assessed to determine if all of the test procedures needed to address a specific requirement have been implemented and whether the test result shows that the required capability has been shown to exist and/or the level of simulation representation meets the referent with the tolerance bounds of the associated acceptability criteria. Test results for derived requirements are rolled up to determine whether or not a high-level requirement is met, partially met or not met.

### 5.2.4.2 V&V Goal Network implemented with the GSN

The V&V Goal Network starts with the Acceptance Goal from which the Acceptability Criteria are derived. The Acceptance Goal is typically a high level statement on the expected utility of the M&S Results to support the Problem Solution, see Figure 9. In the top part of the V&V Goal Network the acceptance planning is documented. There the high level Acceptance Goal is refined into Acceptability Criteria. These Acceptability Criteria are typically still on a level understandable by the stakeholders that use the M&S Results in the Problem Solution and possibly the Real World stakeholders.

To make the Acceptability Criteria measureable some more derivation may be needed. This is the second part of the V&V Goal Network, i.e., the V&V planning. This part ends in the complete specification of the V&V Experimental Frame which is the collection of all evidence solutions. 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.

Choosing the right V&V solution depends on e.g., the required convincing force of the evidence, the available facilities and other resources (see Section 5.2.4.4).

The Goals can contain criteria on utility, validity or correctness (see Section 5.2.1). Utility goal can be decomposed into smaller utility goals but also into validity and correctness goals. Validity goals can be decomposed into smaller validity goals but also into correctness goals. Correctness goals can only be decomposed into smaller correctness goals. Each of the three types of goals can result in the definition of an experiment to obtain evidence. Together these required experiments are the V&V Experimental Frame.

Some parts of the above hierarchy are about the M&S system. In Section 5.1.2 a system is described hierarchically from black box to several grey box views and finally a white box. In the disaggregation of the Acceptance Goal into Acceptability Criteria and ultimately Evidence Solutions, it may be necessary to open up the system to some grey view or even the white view. The disaggregation should stop at a level for which a feasible (with respect to available resources) experiment can be specified that can generate evidence with sufficient convincing force. For V&V, however, it may be necessary to look beyond the M&S system, for example design documents or implementation details.

The disaggregation of a goal in the V&V Goal Network build with the GSN notation [B59] typically looks as shown in Figure 12. Here goal G1 is split into two sub-goals, G2 and G3, but in general any number of sub-goals is allowed.

![Figure 12: Goal refinement in the Goal Network. The conventions of [B59] are used: Goals are rectangles and strategies parallelograms](image)

The strategy, S1 in Figure 12, must show that goal G1 is completely covered by goals G2 and G3. Thus the criterion expressed in G1 is equivalent to the combination G2 and G3. The strategy S1 provides the arguments for this equivalency.

5.2.4.3 V&V Claim Network implemented with CAE

The V&V Results obtained from executing the V&V Experimental Frame and are relevant are called the Items of Evidence (IoE). These IoE are the starting points of the V&V Claim Network. Based on the IoE, claims can be made about the suitability of the M&S System and its use for the intended purpose. At the bottom of the V&V Claim Network, Figure 10 above, these claims have a limited scope just like the goals at the bottom of the V&V Goal Network. But the detailed claims can be integrated into higher level claims. The integration steps need to be well argued, similarly to the use of strategies in the V&V Goal Network.

The GM-VV recommends using the Claim-Argument-Evidence notation for this part of the Argumentation Structure. The aggregation of claims typically looks as shown in Figure 13. There claims C1 and C2 are aggregated into claim C3 by argument A1. In general aggregation of any number of claims is allowed.
Claims are based on lower level claims via arguments. The conventions of [B60] are used:
Claims are ovals and arguments rectangles with rounded corners

The IoE are integrated into Acceptability Claims in a V&V assessment processes, see Figure 10 above. These are the V&V Claim Network equivalents of the Acceptability Criteria in the V&V Goal Network. The Acceptability Claims are further integrated into an Acceptance Claim in an Acceptance Assessment process.

If all Evidence Solutions are matched by a positive Item of Evidence and no unexpected observations were made during the execution of the V&V Experimental Frame, the V&V Claim Network is a mirror of the V&V Goal Network. If some pieces of evidence cannot be obtained, or counter evidence is obtained, or unexpected evidence is obtained the V&V Claim Network can deviate in structure from the V&V Goal Network.

5.2.4.4 V&V Experimental Frame

The Evidence Solutions in Figure 10 above, are the proposed ways to obtain evidence. They specify one or more frame(s) as described in Section 5.1.4. The collection of all these frame(s) forms the V&V Experimental Frame. Every element of the M&S life cycle (see Section 5.1.9), may be examined in the GM-VV.

Traditionally the focus of the V&V effort is on the M&S System and its Employment. In that case the system under consideration is the combination of the Simulation Frame including the M&S System (see Section 5.1.8 and Figure 15 below). Some tests, however, may consider the Simulation Frame or the M&S System separately if evidence can be obtained more effectively or efficiently.
An Evidence Solution specifies a V&V technique (see Section 5.2.5) which requires the following:

- The V&V Experimental Frame instantiation (e.g., input data),
- Referent data to which the output of the V&V Experimental Frame must be compared,
- A comparator that determines the differences between the experimental data and the referent data,
- An evaluator that determines whether the observed differences are within a required tolerance level.

In order to stay within the V&V effort’s resources (e.g., budget, time and SME availability) the V&V Experimental Frame must be examined on resource costs versus expected quality of the evidence it is supposed to produce. This may yield that some tailoring is needed (see Section 5.2.6). This tailoring can concern the whole V&V Experimental Frame or individual Evidence Solutions.

If insufficient resources are available there are methods available to obtain an acceptable Experimental Frame, such as Evidence Solutions that contribute the most to mitigating the critical M&S use risk areas should remain and less important Evidence Solutions can be dropped from the V&V Experimental Frame. It may also be possible to combine several Evidence Solutions into one experiment. The individual Evidence Solutions may also be modified to the available resources.

The V&V Experimental Frame is a specification of the V&V Techniques (see Section 5.2.5) that needs to be implemented and executed. This often includes constructing data sets, building a test harness and executing tests. The execution of the V&V Experimental Frame results in a body of raw data, called the V&V Results. The implementation and execution of the Evidence Solutions should deliver evidence to the needed V&V Results with the required convincing force. However, not all experiments lead to the satisfaction of the originating Evidence Solution. For example, due to practical constraints, the total number specified M&S experiments could not be performed to obtain the required statistical power or confidence level of the experimental data. In such cases the Evidence Solution may have to be re-examined and a different experiment be specified and executed (see Section 5.2.5).

Care must be taken that the V&V Experimental Frame, its execution and the V&V Results are fully linked because the whole Argumentation Structure must be traceable. This means that the V&V results must be carefully documented along with the process of how they have been obtained and constructed.

5.2.5 V&V Techniques

The GM-VV does not focus on standard V&V techniques that can be applied to a specific M&S system or domain. Instead, it provides a universal and systematic approach of organizing, managing and executing the whole V&V effort. The V&V Goal Network, see Figure 10 above, is used within the GM-VV to support the selection of such V&V techniques.

The GM-VV recommends establishing a catalog which documents the various V&V techniques and their properties. Properties that could be documented include:

- domain or M&S technology to which the V&V technique can be applied,
- expected convincing force,
- expected resource cost.

Existing V&V techniques catalogues can serve as a start for the GM-VV catalogue. Example can be found in the MURM method [B4] which are based on the following references [B42], [B43], [B44] and [B45]. The V&V techniques are categorized in Table 1: Overview of V&V techniques below.
Table 1: Overview of V&V techniques

<table>
<thead>
<tr>
<th>Informal</th>
<th>Formal</th>
<th>Static</th>
<th>Dynamic</th>
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</thead>
</table>
Informal V&V techniques are usually executed and interpreted by humans. Typically these require few resources and can be executed in a short time. The convincing force, however, depends on the trust in the humans doing the work and the process they use.

Formal V&V techniques are based on mathematical proofs of correctness. The application of formal methods, however, is often limited due to large resource costs even for relatively small M&S systems and their use. If applicable, the convincing forces of the V&V results are very strong.

Static V&V techniques can be applied early in the development process because no execution is required. It is typically applied in the concept phase and parts of the development phase (see Section 5.1.7). Typically specialized tools are used to do automated checks. The required resources are normally limited. It is required to have access to documentation and half-products. The strength of the convincing force is dependent on the rigor of the tests.

Dynamic V&V techniques require execution of the M&S System in part or as a whole. The dynamic properties of the M&S System are studied and checked. Typically specialized tools are used to do automated measurements and checks. The required resources are normally limited. Dynamic V&V techniques may require access to parts of the M&S System that are usually not available. The strength of the convincing force is dependent on the rigor of the M&S System check.

5.2.6 Tailoring

The GM-VV is written to address generic V&V practices that are applicable to any given organization or system-of-interest. A tailoring process is applied to adapt the processes and activities to the situation at hand. The GM-VV tailoring process is based on standard system engineering processes [3] [B38]. The principle behind tailoring is to execute the GM-VV processes effectively and efficiently.

The GM-VV implementation framework (SISO-GUIDE-001.1-2012, chapter 6) provides the components that may be used to develop a V&V Solution. The GM-VV implementation framework should be tailored to the specificities of every V&V effort.

The purpose of the GM-VV tailoring framework is to customize the GM-VV implementation framework components to satisfy the specific requirements and constraints of but not limited to:

- An organization that employs the GM-VV (e.g., company policies, standards, size, skillset, specialty, maturity level, information security).
- A domain where the GM-VV is employed (e.g., standards, regulations, technologies).
- A V&V supplier entity that delivers V&V products or services (e.g., standards, processes, contracting issues).
- M&S use risk (e.g., criticality and scope of the acceptance decision, M&S use-risk tolerances)
- Scale and complexity of the M&S system
- Resource availability (e.g., time, budget, scale, complexity, skills, infrastructure).

The GM-VV tailoring framework considers three generic organizational levels, enterprise, project and technical that are each divided into two phases: instantiation and operation/execution. To achieve this, the framework utilizes four basic tailoring approaches: extension, reduction, specialization and balancing. During the instantiation phase the tailoring approaches can be utilized to solidify a V&V Solution. The tailoring approaches are applied during the operation/execution phase to optimize the V&V Solution.

The application of these four tailoring approaches is resource and/or risk based [B4][B13][B28][B36][B37] and can be grouped into the organizational levels of the GM-VV implementation framework. Tailoring typically strives towards an optimal V&V Solution that will present evidence for the Acceptance Recommendation but also for the quality of the V&V work itself.
6 GM-VV Applications

6.1 Introduction

In this chapter 9 examples are briefly presented in which GM-VV was applied. The sections below provide some context information on the application, the performed activities and the major findings. For some of the examples more information can be found in papers, in which case references to these papers are added, and copies of the papers can be downloaded from http://sisostds.org.

Example 1 below is based on research experiment on handling highway traffic at an incident location, and was instantiated by the Dutch government.

Example 2 was started by the Royal Netherlands Navy as an R&D experiment to investigate the effects of Heavy weather conditions on human performance of "Officers of the watch".

Example 3 shows how genericness and flexibility of the GM-VV by showing how the GM-VV can be tailored towards other existing standards such that existing experiences can be used for the GM-VV.

These first three examples were performed while developing the GM-VV. The GM-VV terminology was not fully developed by then and therefore not up to date in the referenced papers ([B39][B40][B41]).

Example 4 the main topic is the efficiency and usability of the GM-VV documentation and the tailoring concept.

Example 5 discusses the efforts, efficiency and effectiveness of performing V&V-activities.

Example 6 discusses the use of independent V&V to guide and/or support some V&V activities concurrently with simulation model development.

In examples 4, 5 and 6 were initiated by institutions of the German Armed Forces acting as project sponsor and as user. In each case, companies specialized in the respective field (Szenaris GmbH, ESG GmbH) have been contracted for the design and development of the simulation models. An independent institution (ITIS) was assigned to develop V&V plans, to support M&S documentation, and to support V&V-activities in cooperation with the V&V User/Sponsor and developers.

Example 7, initiated by the Swedish Defence Research Agency, tests the GM-VV on a unclassified air-to-air missile model.

Example 8 evaluates the GM-VV on project and technical level applied to a training simulation concept for the Royal Netherlands Air-Force (RNLAF)

Example 9 evaluates the GM-VV on project and technical level applied to a demonstrator Public Order Management (POM) serious game for the Royal Netherlands Marechaussee (KMar).

The last two examples (8 and 9) are executed by Q-tility. Q-tility is an instantiation of the GM-VV enterprise level. It is a cooperation of two Dutch research institutes (NLR and TNO) specializing in verification and validation solutions for models, simulations and serious-games.

6.2 Example 1: Human Driving Behavior Research Simulator

Overview:

This example is based on [B39]. The "Flashing lights" case was one of the first cases to test drive the GM-VV methodology. This case comprised a recently executed test and evaluation study for Dutch Ministry of Transport, Public Works and Water Management, called Rijkswaterstaat (RWS). For this study the TNO driving simulator was used as a testbed for the investigation of the effects of a new traffic accident signaling strategy.
Traffic density in the Netherlands is so high that when accidents happen on one of the main highways, even other parts of the highway infrastructure is severely implicated. For this reason the RWS, initiated the FileProof research program. This program focuses on research into 60 possible counter measures for traffic jams that can be implemented fairly quickly into the Dutch highway system. One of these possible counter measures is the directive “Flashing Lights Off on Accident Site”. However, before implementing this directive RWS wants to be sure that the directive successfully reduces traffic jams around accident sites (both day and night) and do not impose unacceptable risks for the safety of rescue workers on site. To test this simulation was used.

A minimal confidence level is required on the validity of the experiments to support the claim that, whatever the outcome, the results are indeed acceptable to make a valid conclusion. This depends both on the collected evidence from the driving simulator as well as how the simulator has been utilized in the experimental setup.

![Screenshot showing directive](image)

Figure 16: Screenshot taken during the simulation showing the directive “Flashing lights off on location”

Objectives of the exercise regarding the GM-VV:

- Execute the first NATO GM-VV test case,
- Test the GM-VV documentation on clarity,
- Test the GM-VV documentation on workability,
- Obtain practical experience for how-to documentation.

Major findings and lessons learned:

- As a result of this exercise the then present set of GM-VV documents went through a major restructuring process which also led to a change in the Product Nomination for a SISO Standard,
- This case study led to a reduced GM-VV document set as duplications between documents were removed,
- To fully fine tune the methodology for practical application in a wider community more case studies were necessary.
6.3 Example 2: The Naval Heavy Weather Ship-Handling Training Simulator

Overview:

This example is based on [B40]. In order to be able to operate effectively and safely, the Royal Dutch Navy needs well educated and trained personnel and appropriate doctrine. Currently no specific training for Heavy Weather Ship Handling (HWSH) is available. Learning to handle ships in heavy weather is learned on the job in real world situations under guidance of experienced officers. Training for ship handling in heavy weather situations can be executed in a simulation environment, but it is not known how important the motion component is. This question about motion in the simulation is the focus of an experiment on which V&V was performed.

For this experiment a full motion research simulator, called DESDEMONA, was equipped and prepared to simulate the conditions of a ship in heavy weather. The proposition of the acceptance goal, the GM-VV wording of the actual answer to the main question, was formulated as: "The results of the experiment are useful in the determination of the significance of physical motion in simulation of high sea state for training and doctrine evaluation".

![Desdemona motion simulator (right) with test subject (left)](image)

Figure 17: Desdemona motion simulator (right) with test subject (left)

Objectives of the exercise regarding the GM-VV:

- Tailor the GM-VV activities towards the running experiment,
- Build a GM-VV argumentation structure for the validation of the experiment,
- Execute the Experimental Frame using the experimental set-up where possible,
- Provide the Acceptance Recommendation to the V&V User/Sponsor.

Major findings and lessons learned:

- The GM-VV contains all necessary high level ingredients for a rigorous application of V&V in the large scale M&S based experimental set-up,
- Tailoring has successfully been applied in several ways e.g., during instantiation elements were added and removed from the GM-VV implementation framework, and balancing during construction of the V&V argumentation structure,
- Defining the V&V Experimental Frame for this case-study required extensive balancing of which V&V techniques to apply,
- The GM-VV tailoring principles worked well and resulted in a practical application of the GM-VV.
6.4 Example 3: The VV&A Overlay for the FEDEP

Overview:

This example, based on [B41], shows how the GM-VV can be tailored towards another V&V approach, such that specific techniques of that approach can be applied within the GM-VV context. The choice which method for V&V works best in a given situation depends on the individual needs and constraints of an organization, project, application domain or technology. Moreover, V&V of M&S still is a relatively new field of technology and practice. As a result 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 assets and results from one organization, project, and technology or application domain to the other.

The purpose of the GM-VV is to provide a general baseline and guidance for V&V of M&S that:

- facilitates a common understanding, communication, comparison and interoperability of native V&V practices and standards
- is applicable and tailorable towards individual V&V needs of a wide variety of M&S technologies and application domains

This case study shows that GM-VV is a generic approach such that other existing V&V approaches can be considered to be an instance of the GM-VV. This is used to mutually reinforce the various V&V approaches: the GM-VV can use existing practices and the other approaches may use e.g., the structured approach of the GM-VV.

One often used V&V approach is the IEEE Recommended Practice for Verification, Validation and Accreditation of a Federation provides a VV&A overlay to the FEDEP [5].

The goal of this paper is to show how the VV&A overlay can be derived via tailoring of the GM-VV as an M&S technology specific V&V application instance. As such it helps the M&S community to better understand the purpose of the GM-VV, its usage, added value and relationship to other V&V standards.

![Diagram of GM-VV products and VV&A overlay products](image)

Figure 18: The GM-VV products (light grey) and its coverage by the VV&A overlay products (black ovals)

Activity objectives regarding the GM-VV:

- Demonstrate how the existing Verification, Validation and Accreditation (VV&A) overlay to the FEDEP [5] can be derived from the GM-VV,
• Provide the mapping between the VV&A overlay terminology, definitions and concepts, and the
generic ones provided by the GM-VV conceptual framework,
• Provide detailed mappings of the VV&A overlay roles, processes and products onto the GM-VV
generic building blocks provided by the GM-VV implementation framework.

Major findings and lessons learned:

• The most important conclusion of this work is: the VV&A overlay to the FEDEP can be considered
to be a tailored instance of the GM-VV,
• This tailoring case-study provides an item of evidence for / or shows the genericness of the GM-
VV,
• The VV&A overlay deletes (reduction approach to tailoring) almost all the aspects related to the
GM-VV enterprise and project level,
• The VV&A overlay can be seen as a specialized implementation of the GM-VV technical level
products, processes and roles,
• It is shown that the VV&A overlay user may benefit from using the overlay in concert with GM-VV:
by using the GM-VV products, processes and roles on project and enterprise level they could
increase the effectiveness and efficiency of the technical V&V work described by the VV&A
overlay.

6.5 Example 4: Pioneers Pontoon Bridge

Overview

In context of the development of a team training simulator for coordinating actions that have to be taken
to assemble different parts of a ribbon/floating bridge for crossing a river (as shown in Figure 19), major
experiences have been gained from application of a project and model documentation process according
to national guidelines adapted to GM-VV guidelines According to general process, product, role and
tailoring guidelines, the project was processed cooperatively by a team including representatives of the
project sponsor (BWB), M&S developers (Szenaris GmbH), and an independent V&V-Enterprise / Project
Manager (ITIS). While the M&S developers were designing and implementing the simulation model
according to the V&V User/Sponsor needs, they had to provide process and model documentation for
each model development phase in accordance with these guidelines. In this case study, ITIS provided
guideline coaching and evaluated the quality of model documentation in form and content.
Objectives of the exercise regarding the GM-VV:

- Coaching the application of a national process and documentation guideline which is in accordance with GM-VV,
- After deriving Acceptance Criteria, the tailoring of the M&S process was supported to comply with the criteria,
- Estimation of V&V resource costs (SME effort, budget) by sample application of V&V techniques to M&S products,
- Gathering feedback from sponsor and developers regarding the general documentation structures and guideline concept.

Major findings and lessons learned:

- Basically, the proposed V&V documentation structures and guideline was perceived as time-consuming but also as beneficial by the M&S developer. After this cause study, the company decided to apply this guideline in other projects on its own initiative,
- IPR and know-how protection has been seen as a critical issue related to model documentation and (independent) model V&V.
- Resource costs of the V&V effort should be estimated as early as possible. Since total project budget and the quality of the results depend on tailoring decisions, these should be accepted and well documented by all contributing parties.

6.6 Example 5: Robot Movement Simulator

The goal of this case study was to investigate acceptance, feasibility and involved efforts / costs for development and application of a V&V-Plan in the context of the robot simulator project (Figure 20). For budgetary reason, the scope of this case study was tailored to the V&V of a subset of the model development phases, and to three of the thirteen predefined application scenarios in which the simulator is intended to be used.
Objectives of the exercise regarding the GM-VV:

- Supporting the verification of the model documentation (e.g., regarding completeness, consistency),
- Development of a V&V Plan as a result of the tailoring during instantiation based on the project requirements, the case study budget and in cooperation with sponsor, developer and V&V project and technical level roles,
- Cooperative decisions regarding additional tailoring activities during operation/execution (together with the sponsor and the developer),
- Execution of V&V activities and documentation of V&V results according to the V&V plan,
- Sample application of different V&V techniques to investigate their effectiveness.

Major findings and lessons learned are:

- The V&V implementation framework concept can be applied for process management tasks (such as planning, organizing, and monitoring the V&V effort) as well as for technical tasks (like analyzing, evaluating, reviewing, and testing model elements),
- Both phases of tailoring (instantiation and operation/execution) are indispensable,
- Regarding IPR and know-how protection, the following white box/black box test procedures was proposed:

1. The independent V&V Enterprise / Project Manager in cooperation with the V&V User/Sponsor specify detailed V&V requirements, acceptance criteria and measures and contents of V&V reports for model work products subject of V&V;
2. An internal inspector on the M&S developer side (e.g., from the quality assurance department) performs the specified white box examination according to the V&V requirements, and documents the V&V process and its results;
3. The V&V Enterprise / Project Manager evaluates correctness and validity of the model, simulation and data based on the (black box) V&V results and prepares an acceptance recommendation.
6.7 Example 6: Guidelines for Platoon Commanders

Goal of this simulation project was to be able to analyze different guideline options for platoon commanders, how to lead his or her platoon in different and safety-critical scenarios (as shown in Figure 21, e.g., w.r.t. driving velocity of tanks, distance between vehicles, velocity etc.). One of the project requirements defined a limited time frame for simulation model development and availability of the requested simulation results. Beside this time limitation, quality of the modeling process and its results should be evaluated through V&V. Therefore, as a case study, ITIS as an independent V&V Enterprise / project Manager was assigned to guide or support some V&V activities concurrently with simulation model development.

Objectives of the exercise regarding the GM-VV:

- Supporting the verification of the model documents especially for completeness and consistency,
- Preparation of the V&V plan (in cooperation with the project sponsor and the M&S developer),
- Selecting V&V techniques and conducting V&V activities according to the V&V plan,
- Documentation of the V&V results.

Major findings and lessons learned have been:

- The generic tailoring framework of the GM-VV was applied and has confirmed its usability. In total, applying instantiation and operation/execution tailoring actions according to the project requirements and constraints, 8 versions of the V&V plan were developed. The first version was prepared based on instantiation tailoring, all the others were results of operation/execution tailoring needs,
- Because of the vague V&V User/Sponsor Need specifications the focus of V&V was directed towards an evaluation of the Structured Problem Description (SPD) and the Conceptual Model (CM) development,
• A combination of different V&V techniques (e.g., combination of Inspections, Face Validation, and Visualization/Animation in this case study) was very useful very effective.

Time and efforts required for execution of V&V techniques and interpretation of V&V results has to be estimated at the begin of a project based on project constraints and requirements. Experience showed that just time scheduling requirements and availabilities of M&S developers and V&V Implementers, have to be considered as limiting factors for processing certain V&V activities This experience indicated the need for operation/execution tailoring actions, and a revision of the V&V Plan.

6.8 Example 7: Air-to-air Missile

Overview

This example is based on [B70] reporting on a case where the GM-VV has been tested within the Swedish Defence Research Agency (FOI) on an unclassified model of a generic air-to-air missile. The intended use of this missile model was training of fighter pilots in beyond-visual-range (BVR) scenarios, thus aimed at being Suitable for Air Combat Training.

The exercise involved a team of M&S developers using requirements specifications on this generic model coming from project sponsor organizations such as the Swedish Armed Forces and industrial partners. The GM-VV has been used to refine and elaborate on these requirements specifications to derive an acceptance recommendation for the intended use of the model. Three top requirements on the model have been selected to test and apply the GM-VV (Figure 22):

• Sufficient realism; choices of physical modeling in terms of structure and sub models reflecting the vital components of a BVR missile.
• Sufficient transparency; information regarding the interaction between the missile and all surrounding objects (target, environment, etc.) to be displayed to the pilot during flight but also for post mission review.
• Be executable in a simulator; use of MERLIN, a component based simulation framework for soft real time simulations of weapon platforms, to run the missile model.

Figure 22: Requirements breakdown for the air-to-air missile model.
Objectives of the exercise regarding the GM-VV:

- Test the applicability of the methodology,
- Coach the application of the GM-VV process,
- Support the development of the Goal-Claim Networks,
- Support the tailoring of M&S process and documentation activities,
- Gather feedback from M&S developers regarding utility and benefits of using the GM-VV, highlighting particular aspects of the methodology being more relevant/useful as well as ones that are less relevant/useful that need be improved.

Major findings and lessons learned:

- GM-VV is a promising method for the validation of missile models, and should also be suitable for other applications. A strength of the method is the clear link to the application and targets with the model,
- With a structured V&V methodology created, a documented and transparent chain of evidence between the declared objective of the model and the assertion that the model lives up to the goal,
- The importance of a thorough requirements definition and formulation of the intended use of the model has been clarified in the work. In the reported example it has been found that a simpler model of the missile, could have had fulfilled the use area so as described herein,
- The work carried out has also further demonstrated the utility of a close dialogue between V&V implementers, M&S developers and users.

6.9 Example 8: Distributed Air Operation Mission Training Environment

Overview

This example is based on [B62] and [B63]. In order to be able to operate effectively and safely, the Royal Netherlands Air-Force (RNLAF) Air Operation Control Station (AOCS) needs fighter controllers that are familiarized with F-16 cockpit operations. Until recently, fighter controllers were trained for this purpose by several familiarization flights in the RNAF F-16B dual seat aircraft. For economic reasons the RNLAF has phased out all its F-16B aircraft. Therefore, AOCS has to find alternatives to continue this type of fighter controller training. A simulation-based training system could provide the fighter controller a cost-effective and safe learning environment in which fighter controllers can experience F-16 flight operations in realistic mission scenarios. To support the concept development and specification phase of such future simulation training environment, a prototype was developed by the Dutch National Aerospace Laboratory NLR. This prototype integrates NLR’s four existing fixed-based F16 flight simulators, a constructive simulation that provides computer generated air threats, and two real-life and NATO classified fighter controller working stations (MASE) into a single distributed air operation mission training environment. Interoperability between all simulation assets was accomplished through DIS.
A V&V study was requested to assess the utility and validity of this training simulation concept and its underlying technology for intended use of AOCS. Based on the acceptance recommendations of this V&V study AOCS would take decisions regarding the acquisition process of a new alternative training environment (e.g., go-no-go decision for an M&S system or M&S requirements refinements). The GM-VV is the recommended standard for V&V within the Dutch MoD. Therefore this methodology was selected for this study. Since AOCS didn’t have the GM-VV knowledge and expertise they contracted (i.e., through the GM-VV recommended V&V agreement) the Dutch V&V service supplier organization Q-ility to perform the V&V. As a V&V User/Sponsor AOCS was actively involved in the V&V work (e.g., review of the V&V argumentation structure, V&V plan approval and SME provision in the V&V execution phase) and was kept up to date on the V&V progress by Q-ility though regular V&V progress reports.

Objectives of the exercise regarding the GM-VV:

- Evaluate the utility of the GM-VV project and technical level components for the V&V of (LVC) distributed simulation applications,
- Establish a tailored instance of GM-VV in the form of a reusable V&V life cycle model by applying the GM-VV tailoring framework Phase 1: instantiation [GM-VV Vol. 2 SISO-GUIDE-001.2-2012],
- Evaluate and refine the yEd tool for V&V argumentation structure and standard office tools (e.g., MS-Word, MS-Excel, MS-Project and MS-Sharepoint) to support the GM-VV process activities, document and manage the GM-VV information artifacts,
- Develop an initial basis for a M&S risk-analysis and reporting approach that could be applied as future concrete technique for “tailoring by balancing” in the GM-VV tailoring framework Phase 2: optimization [GM-VV Vol. 2 SISO-GUIDE-001.2-2012].

Major findings and lessons learned:

- The GM-VV project and technical level components showed sufficient utility for a satisfactory V&V of this (LVC) distributed simulation application,
- The yEd tool and the standard office application based GM-VV support tools showed to be effective and efficient for this V&V study,
- The V&V of the classified simulation application MASE required additional V&V planning, time and resources to complete the V&V study compared to the non-classified simulation applications. Furthermore, V&V configuration and information management process required more attention, effort and more formal implementation.
6.10 Example 9: Public Order Management Serious Game

Overview:

This example is based on [B64]. TNO examined how commanders can learn to maintain public order in their area of operations. Serious gaming proves to be an effective and efficient learning tool. Q-tility has performed an explorative V&V study to the added value of a demonstrator Public Order Management (POM) serious game. The study results show its added value as well as extensions to the current game. One of the POM game users is the Royal Netherlands Marechaussee (KMar). The game can potentially be used for a number of training objectives. With V&V the KMar instructors want to find for what objectives the game is already suited, and what needs to be adapted in order for the game to have utility for the full set of training objectives.

The added value of Q-tilities V&V approach is that it takes more than just the technical game aspects into account: they also examine and give advice on the required personnel, effective and efficient use of a game in combination with other available training methods and even gaming relevant policies that can enhance the added value of the game.

![Figure 24: Public Order Management Serious Game](image)

Objectives of the exercise regarding the GM-VV:

- The KMar trainers and various subject matter experts hired by Q-tility derived the acceptance criteria from the main goal: the game must ensure that training objectives are achieved more efficiently and effectively,
- Further define templates for GM-VV documents,
- The V&V tests consisted of two full training sessions, 4 days in total, in which KMar personnel used the POM game as they intend to use,
- V&V techniques included interviews, observations, 360° assessment, and hardware/software inspections.

Major findings and lessons learned:

- The V&V results confirmed many of the strengths and weaknesses of the game,
- The added value of V&V is that now sufficient - and independently obtained - data is available to back up these claims,
- The POM game developers also appreciated the independent view on the usefulness of the game to prevent tunnel vision in the development team,
- Immediately after the V&V tests the KMar has started implementing changes to allow for efficient and effective use of the POM game.
7 Bibliography

(Informative)


[B9] Traore M., Capturing the Dual Relationship between Simulation Models and their Context.


[B14] Uncertainty; Risk; Dependability from Wikipedia.


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[B34] Rahwan I., et al., On Building Argumentation Schemes Using the Argument Interchange Format

[B35] ITOP, General procedure for planning, implementing, and documenting Verification & Validation efforts relating to Models and Simulations to support the exchange of this information, February 2004.


[B64] Voogd J., M. Roza, A. Lemmers, “Implementing GM-VV enterprise, project and technical levels”, 2013, Fall SIW Proceeding, 13F-SIW-003.