

Conceptual Model Development and Validation

Introduction

The term “conceptual model” has different connotations in different application domains. Law¹ noted that “although effective conceptual modeling is a vital aspect of a simulation study, it is probably the most difficult and least understood.” This condition continues for simulation-related conceptual modeling in general, as indicated by Robinson et al.,² when they observe that “the notion of conceptual modeling, as expressed in the modeling and simulation (M&S) literature, is vague and ill-defined, with varying interpretation as to its meaning.” This leads to their conclusion that “conceptual modeling is more of an ‘art’ than a ‘science’ and therefore it is difficult to define methods and procedures.” To limit ambiguity and in keeping with the context of the Recommended Practices Guide (RPG), this Special Topic addresses the application domain of M&S for simulation-related conceptual models as applied within the Department of Defense (DoD).

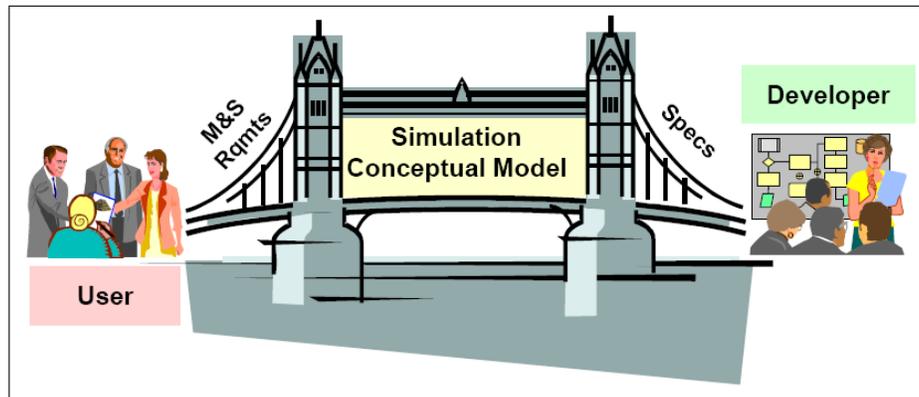
Any simulation can be viewed as a product and any product can be characterized by its life cycle. There are many representations of a simulation product’s life cycle, each of which has at least five phases: Definition, Design, Implementation, Testing, and Maintenance.^{3,4,5} As implied by the term “life cycle,” these processes tend to repeat, so that even as the software product development is completed, it is being prepared for improvement or revision. Similarly, there are numerous descriptions of product development cycles which invariably include the development of a conceptual description or model.^{6,7,8} Generally, the development life cycles include Requirements Definition, Concept Development, Coding, Testing, and Deployment.

As one would expect, there are many interpretations of the term “conceptual model” even within the M&S community. Some use the term for anything conceptual within the M&S development life cycle, including the problem formulation phase. This is particularly true for what some call “business oriented” simulation, most of which have only a few staff months (or less) invested in M&S development, because often one person does everything in the life cycle.²

The M&S community also uses the interpretation of the conceptual model as applied to data. Articles about conceptual models in the *Journal for Conceptual Modeling* focus mainly on database structures and database processes, with obvious attention to such issues as maintaining data integrity. In the late 1990s the Conceptual Models of the Mission Space (CMMS), later called the Functional Description of the Mission Space (FDMS), provided a specialized expression of domain knowledge for military applications. CMMS was “the first abstraction of the real world that serves as a frame of reference for simulation system development by capturing the basic information about important entities involved in any mission and their key actions and interactions.”⁹ The Swedish Defence Research Agency

expanded the CMMS approach into the Defence Conceptual Modeling Framework (DCMF), with emphasis upon its knowledge engineering aspects (knowledge acquisition, knowledge representation, knowledge modeling, and knowledge use) to help capture domain information.¹⁰ This is essentially a method for describing the referent or simuland.

The purpose of this Special Topic is to provide a framework for the development and validation of the conceptual model of the simulation, frequently described as the bridge between the Developer and the User. It serves as a primary mechanism for clear communication among simulation development personnel (software designers, code developers, system engineers, system analysts) and members of the user community (Users, functional area subject matter experts [SMEs], testers, V&V Agents, Accreditation Agents). In this sense, the simulation conceptual model is the “Developer’s way of translating the requirements into a detailed design framework, from which the simulation can be built.”¹¹



Simulation Conceptual Model: The Bridge Between Developer and User

Two Varieties of M&S Conceptual Models: Simulation Conceptual Model and Federation Conceptual Model

Topic Organization

This discussion has two parts. First it addresses the Simulation Conceptual Model for standalone simulations. Then, the Federation Conceptual Model is discussed for groups of simulations working together. The terms federation conceptual model and federation may be used in this Special Topic in the technical sense related to a collection of simulations working together in accordance with the High Level Architecture (HLA) construct, but the terms federation conceptual model and federation are also used in a more general sense relative to a collection of simulations working together regardless of what protocol or architecture may be used.

In both application domains (standalone and federation), the conceptual model and its role in the simulation development life cycle will be examined with particular attention to conceptual model development, management, and assessment. Because there are many functional and process similarities between

simulation conceptual models and federation conceptual models, the discussion of management and assessment aspects applies universally with occasional embellishments for federations as necessary. In addition, a federation may have to comply with particular standards for development of the federation, such as is the case for HLA federations. Comparable standards do not exist for standalone simulation development.

Because it serves as the receptacle for all the information used to define the simulation with respect to an intended use, the conceptual model is the key factor in bounding the development or modification of the simulation. The information contained in the conceptual model determines the substance of what should be included in and excluded from the simulation and also defines the fidelity needed by the simulation to address the intended use. This information can also be used to support articulation of the referent for simulation development and of the referent for simulation validation relative to the intended use.

Conceptual Models and the Referent

Key to conceptual model development and assessment (i.e., verification and validation [V&V]) is how well the conceptual model captures and compares to the referent. The referent is the best information available that describes characteristics and behavior of the reality represented in a simulation. Fidelity measures the degree to which the simulation represents the simuland in absolute terms; validity is the relative determination of whether or not simulation fidelity is adequate to satisfy the intended use.

If a federation is being developed in accordance with material in the verification, validation, and accreditation (VV&A) overlay to the Federation Development and Execution Process (FEDEP), some of the activities identified below for the federation conceptual model development team will have been done by VV&A personnel, before federation conceptual model development begins.¹² Documentation of acceptability criteria, and identification and assembly of the federation referent are two such things. In such a situation, the federation conceptual model development team should include that in the federation conceptual model.

The conceptual model should specify what authoritative information will be used as the referent for fidelity assessment and make clear what information will be used as the standard with which simulation results will be compared during validation (i.e., the validation referent). The information used as the referent may consist of data (results from experiments, tests, and observations; the data from specific tests and sometimes the tests themselves may be called “benchmarks”), algorithms, theories (including the implicit theories used in SME assessments), and combinations of these. The conceptual model may provide pointers to such information located elsewhere or the actual information may be included in conceptual model documentation.

The way that particular entities and processes are represented in a simulation can be very different from the way that the information comprising the referent is described, as illustrated in the examples cited below.

Example 1

Information about the referent describes detailed behaviors (decision delays and likelihood of various decisions) for each of the several members of a combat team. Because of the level at which the simulation addresses the situation, it aggregates the behavior of the team and uses a single distribution for the likelihood of a particular decision with a specified (constant) time delay.

Example 2

Information about the referent describes a complex algorithm (e.g., a hydrocode) that involves several hours of processing by a supercomputer to characterize a few milliseconds of interactions between entities (e.g., the collision between a kill vehicle and its target in ballistic missile defense) and a large collection of test data. The simulation must represent such interactions in real-time or faster, and chooses to use a semi-empirical but physically representative algorithm. In this case, the semi-empirical algorithm becomes the referent.

In cases where explicit data, algorithms, and theories do not provide a comprehensive and reliable description of reality, SME knowledge may have to serve as the referent for fidelity and validation assessments, which generally means that such assessments are predominately qualitative. Such use of SMEs impacts the credibility of the simulation and raises questions about repeatability of the assessment if other SMEs should be used. When this situation occurs, the conceptual model may identify the specific SMEs or kinds of SMEs that will provide the fidelity and validity referents for the conceptual model and for simulation development and assessment. The conceptual model may also indicate processes that the SMEs should use. For more information see [Advanced Topics>Special Topics>Developing the Referent](#) and [Advanced Topics>Special Topics>Subject Matter Experts and VV&A](#).

Implementation Independence

Implementation independence is an important aspect of each conceptual model component, particularly during development. Implementation independence means that the conceptual model should not unnecessarily determine or constrain the nature or contents of acceptable simulation design. However, just as a simulation design matures from a preliminary design to a detailed design, a conceptual model can evolve into one that includes aspects that determine or constrain acceptable simulation design because of explicit or derived simulation requirements; identification of critical assumptions underlying simulation requirements, acceptability criteria, or both; or constraints specified and decisions made by the User or simulation sponsor.

Thus, implementation independence is desirable, particularly during the initial development of the simulation conceptual model, because it supports a more flexible approach to simulation design. Components of the simulation conceptual model should include every dependency necessitated by simulation requirements or constraints, assumptions, and decisions from the simulation User, sponsor, or both. In all situations, the conceptual model should strive for “reasonable” implementation independence (as a whole or in its parts).

Implementation independence should be assessed by examining the conceptual model components to identify what aspects may have implementation dependencies. Then these should be evaluated to determine if a dependency has a negative effect on the conceptual model’s ability to satisfy the federation objectives or to represent simulation requirements for the intended use. Any such implementation dependency should be avoided.

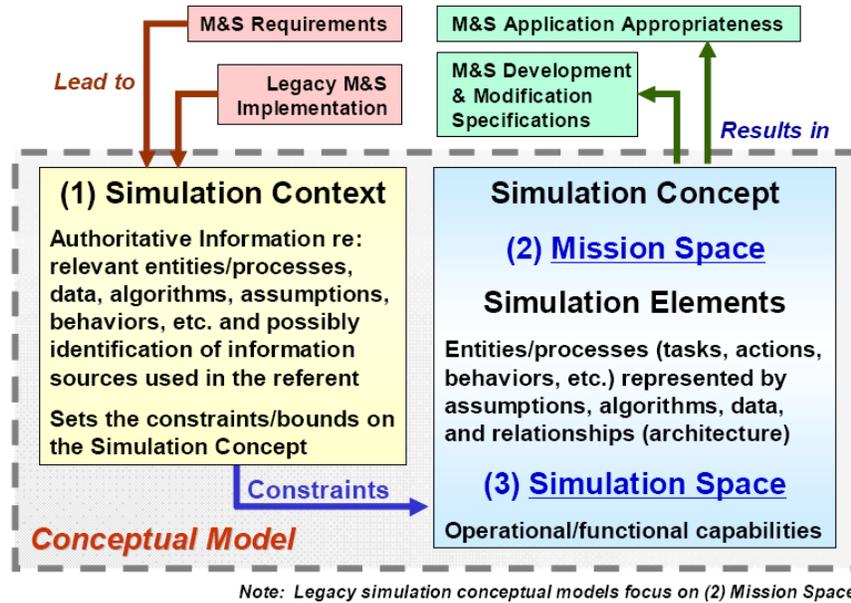
Conceptual Model Description and Development

First, the development of both the simulation conceptual model and the federation conceptual model will be discussed independently. This is followed by discussion of conceptual model management and finally conceptual model assessment. If the term “conceptual model” is used, it is implied that the discussion applies equally to conceptual models of both standalone and federated simulations.

Simulation Conceptual Model Description

What Does a Simulation Conceptual Model Consist of?

A simulation conceptual model consists of three categories of information about the simulation and its intended use: the simulation context, the simulation concept, and the simulation elements, shown in the following diagram.



Simulation Conceptual Model Components

Simulation Context

The simulation context provides authoritative information about the user and problem domain(s) to be addressed in the simulation on the basis of simulation requirements for the intended use. Often the simulation context is merely a collection of pointers and references to the sources that define behaviors, relationships, characteristics, and processes for things to be represented in the simulation. Such sources may include authoritative data sources related to the topic addressed by the simulation.

The simulation context should contain such things as sources for the coordinate systems, algorithms used for calculating radar signal propagation, the operational modes possible for particular pieces of equipment, and the organizational structure and possible information-flow paths of a military unit. In addition, the simulation context is normally where referent data (used in validation) are identified.

The simulation context establishes the boundaries within which a Developer can properly build or modify a simulation for an intended use. It provides the information needed by the User, Accreditation Agent, and V&V Agent to determine if the simulation represents the appropriate domains.

Typically, information in the simulation context is considered implementation independent when the information is not tied to a particular software paradigm or hardware configuration. However, this is not always possible. In a legacy situation, when a simulation context item is reused, that item may be stated in a manner that maximizes compatibility with the previous development and thus may be expressed in a manner that is implementation dependent (such as using a particular software paradigm). Even in a new simulation development, the scope of

the intended use or constraints on resources may force use of a specific language, software, hardware, or data.

The simulation context establishes constraints and boundary conditions for the simulation concept.

Example

If the simulation is concerned with realistic representations of missiles or aircraft in flight, then the laws of physics and the principles of aerodynamics are part of the simulation context and require (constrain) the simulation concept to accommodate conservation of momentum, etc. Unrealistic, cartoon representations of missiles or aircraft in flight would not necessarily be so constrained.

Simulation Concept

The simulation concept serves as the mechanism by which simulation requirements for an intended use are transformed into detailed simulation specification and then into an associated simulation design. It describes the Developer's concept for what is needed to satisfy the simulation requirements and provides the User, Accreditation Agent, and V&V Agent with information needed to determine if the simulation representations are correct and if the simulation controls are acceptable for the intended use.

The simulation concept has two primary aspects: mission space and simulation space:

- **Mission space** is concerned with representation. It includes the simulation elements (e.g., entities, entity attributions, and computational algorithms).
- **Simulation space** is concerned with simulation control. It includes operational and functional aspects of the simulation (e.g., run time requirements, hardware configuration, software operating system specification).

The simulation concept describes in detail all the representations needed in the simulation, the computational basis for represented interactions, and constraints imposed by the simulation's operational environment.

The simulation space component of the simulation conceptual model is seldom totally implementation independent, particularly in the case of the legacy simulation application. If some aspect of a previous simulation implementation (e.g., the architectural limitations of a simulation software implementation, the hardware configuration, the time management process for the simulation) is being reused, it can drive and constrain the how the conceptual, and ultimately the simulation design, is developed.

Simulation Element

A simulation element is the collection of information describing the "world" to be simulated. Elements include a description of the representational capabilities need to address the requirements and intended use. Typical components of a simulation element are listed in the following table.

Components of a Simulation Element
• Entity, process, or collection definition
• Assumptions about, limitations of, and constraints placed on the element
• Algorithms and algorithm pedigrees
• Data and data history
• Relations with other things within the simulation
• Interactions with other things within the simulation

An example showing the range of possible simulation elements is shown below.

Examples

A simulation element can address a complete system (a missile or radar), a subsystem (the antenna of a radar), an element within a subsystem (a circuit within the transmitter of a radar), or even a fundamental item of physics (an atom).

A simulation element can address composites of systems, such as a ship or aircraft with its collection of sensors and weapons, a person, part of a person (a hand, for example), or a group of people.

A simulation element can address a process such as environmental effects on sensor performance.

Implementation independence has significant impact when defining simulation elements. Sufficient description of the elements is required to ensure correct interpretation by the simulation developer, but the description should not constrain the developer's ability to construct an efficient, effective simulation architecture.

What Information Should a Simulation Conceptual Model Include?

A list of the types of information that should be considered for inclusion in a simulation conceptual model is provided in the table below. For additional detail see [Resources>Templates>Conceptual Model Template](#).

Example List of Information Included in a Simulation Conceptual Model
1) Simulation descriptive information
<ul style="list-style-type: none"> • Simulation identification and simulation conceptual model identification (e.g., name, version and date for each) • Points of contact • Simulation and simulation conceptual model change histories (with relation to any changes in simulation requirements)
2) Simulation context (per intended use)
<ul style="list-style-type: none"> • Purpose and intended use statements • Pointer to simulation requirements documentation • Overview of planned simulation capabilities • Pointer to authoritative data sources relative to the domain of interest and/or other sources of domain information • Constraints, limitations, assumptions • Pointer to validation referent and referent information
3) Simulation concept (per intended use)
<ul style="list-style-type: none"> • Mission space representation <ul style="list-style-type: none"> – Simulation elements (link to description defined in #4) – Simulation development environment artifacts (e.g., UML diagrams) • Simulation space functionality • Description of simulation space impact on simulation element representation
4) Simulation elements, including
<ul style="list-style-type: none"> • Entity definitions (entity description, states, behaviors, interactions, events, factors, assumptions, constraints, etc.) • Process definitions (process description, parameters, algorithms, data needs, assumptions, constraints, etc.)
5) Validation history, including
<ul style="list-style-type: none"> • Simulation requirements and objectives addressed in V&V effort(s) • Pointer to validation report(s), especially the conceptual model validation report • Pointer to simulation conceptual model quality assessment(s) • Description of simulation conceptual model change history
6) Summary
<ul style="list-style-type: none"> • Existing simulation conceptual model limitations (for intended use) • List of existing simulation conceptual model capabilities (for intended use) • Simulation conceptual model development plans

What Can a Simulation Conceptual Model Do?

The simulation conceptual model has two primary functions: to facilitate both simulation development and assessment. As the means by which simulation requirements can be transformed into simulation specifications that then drive simulation design, the simulation conceptual model facilitates simulation development. A simulation conceptual model may precede many simulation design and implementation decisions, allowing the simulation conceptual model to be largely independent of design (and implementation). However, in some situations, a simulation conceptual model will include design considerations, especially when parts of the simulation are reused from a previous simulation or

when it is decided *a priori* to use a particular hardware or software environment for the simulation. Sometimes, the simulation conceptual model will even be expressed in the descriptive environment chosen for simulation development or one of the formal method paradigms employed when assured correctness is required. The simulation conceptual model facilitates simulation assessment by providing information about how the simulation might perform in areas where it has not been tested. This is very important, because simulations are often used to explore situations for which test data and observations are not available. It helps to know whether simulation results in such circumstances can be trusted or whether they must be viewed with skepticism. The simulation conceptual model provides a logical and factual basis for such an assessment. Thus, the simulation conceptual model plays a vital part in simulation VV&A.

Some simulation developments fail to create distinct documentation for the simulation conceptual model. This invariably leads to difficulties later.² When one has to use a legacy simulation whose conceptual model is inadequate or non-existent, collecting the information can significantly increase the cost of the V&V effort.

How Can a Simulation Conceptual Model Be Used?

Simulation conceptual models can be used for a variety of purposes, some of which are listed below.

Simulation Conceptual Model Applications
• As a basis for assessment of simulation appropriateness for a particular application
• As a context for results validation
• As a foundation for design of software and other components for new and modified simulations
• As a basis for effective and efficient communication about the simulation and its capabilities among Users, Developers, those involved in simulation-related assessments, and others
• As a tool for enhancing understanding of simulation requirements and their implications for simulation capabilities and costs
• As an important aspect of simulation design/implementation verification
• To facilitate reuse of simulation components in simulation development and evolution

The simulation conceptual model provides a rational basis for judgment about the appropriateness of a simulation for use in situations that are not explicitly tested. It provides a context for results validation so that one has a basis for judgment about acceptability of interpolation or extrapolation of simulation results relative to validation referent data. During simulation development or modification, the simulation conceptual model is a means by which simulation requirements can be transformed into simulation specifications that then drive simulation design.

The effort required to develop a simulation conceptual model is justified in two ways:

- The first justification comes from potential savings in simulation development time and costs. A comprehensive simulation conceptual model helps to identify problems in simulation requirements before the simulation is designed and implementation begins. This avoids many design and implementation problems and the potential cost and delay of rework resulting from the problems that arise from faults in the simulation requirements. Requirements faults are one of three major causes of software faults, including those encountered in simulation development.¹³
- The second justification comes from the importance of appropriately using a simulation for its intended uses. When a simulation is involved in critical decisions, whether in support of planning, analysis, design, operation, or training, a simulation conceptual model increases the likelihood that the simulation will be used correctly and that appropriate use is made of simulation results.

Where Can a Simulation Conceptual Model Be Found?

Ideally, the simulation conceptual model is developed as an artifact of the simulation development process and maintained as part of the simulation configuration management process. However, if a simulation is or was constructed without a formal simulation conceptual model (i.e., the simulation conceptual model was not specified as a contractual “deliverable”) or if a simulation conceptual model has not been well maintained during the simulation’s product life cycle, then the V&V Agent will need to develop a surrogate simulation conceptual model from existing simulation information products (descriptive information, diagrams, algorithms, behaviors, performance data, scenarios, constraints, representations, limitations, interactions, operational and mission descriptions). Once developed, the simulation conceptual model should be maintained by employing a configuration management process along with other simulation artifacts such as the requirements, the design, and the code.

What Does a Simulation Conceptual Model Look Like?

The great variety of DoD M&S applications makes it difficult to predefine a form or structure that would be appropriate for all conceptual models. The simulation conceptual model is a product of simulation development and therefore is tied to the development tool and/or method (e.g., UML, SysML). Simulation conceptual models have appeared in various ways, a few of which are indicated below.

- Some have followed the ideas of Jacobson et. al.¹⁴, who emphasize use cases in object-oriented software developments and let the use cases serve to shape the simulation conceptual model in the transition from requirements to design in software development. Such approaches often fail to capture all information desired in a simulation conceptual model. For example, there is no standard way to capture assumptions and algorithm pedigree in use case approaches.
- To facilitate compatibility with descriptions of the simulation context, simulation conceptual model development may use knowledge engineering

techniques such as those emphasized in the DCMF¹⁰ and various authoritative data sources that have employed knowledge engineering constructs.

- In the late 1990s, when emphasis began to be placed on the simulation conceptual model as a distinct simulation development artifact, it was noted that four primary ways were being used to document simulation conceptual models.¹⁵ The *ad hoc* approach was noted as the most common approach at that time, and the scientific paper variety of simulation conceptual model documentation was recommended as the best approach.
- The Department of Defense Architecture Framework has been suggested as a descriptive method for simulation conceptual models.
- Unified Modeling Language (UML) and its variations such as Systems Modeling Language (SysML) have been used to describe simulation conceptual models for a number of simulation applications.¹⁶ Some have exploited the potential of the UML approach to automate some aspects of simulation conceptual model development and use.²
- Some have drawn upon simulation user or analyst manuals with some additional information to serve as surrogate simulation conceptual models for legacy simulations that did not have explicit simulation conceptual models.

Regardless of the shape it takes, the simulation conceptual model should present a coherent set of information that fully and correctly describes the simulation conceptual model so that simulation capabilities, limitations, and characteristics can be readily understood by the User, Developer, V&V Agent, and SMEs involved in simulation assessments. The simulation conceptual model should also provide traceability back to the simulation requirements, describing which sections of the simulation conceptual model apply to which requirements.

Simulation Conceptual Model Development

The material in this section describes the simulation conceptual model development process and then discusses the issues of reality abstraction and identification of problems in simulation conceptual model development.

The simulation conceptual model development process applies to both new simulation developments and to modifications of legacy simulation applications. For a legacy simulation without an adequate simulation conceptual model, VV&A personnel will have to generate a surrogate simulation conceptual model if they are to do a thorough job of assessing the simulation. Those who create the surrogate simulation conceptual model will have to use available information, and perhaps employ many of the steps in the simulation conceptual model development process below. This Special Topic will not try to provide separate guidance for development of such surrogate simulation conceptual models. Should

such a legacy simulation be modified, the Developers should produce a simulation conceptual model that documents the simulation including the modification.

A simulation conceptual model provides a way of translating the simulation requirements for the intended use into a detailed design framework, from which the simulation (which may include software, hardware, systems, and/or people) can be built. There are five basic steps involved in developing a simulation conceptual model, which may be iterated a number of times throughout the development process as requirements change or modifications are made to design, data, or code. These are listed below and discussed in the following paragraphs.

- 1) Collect authoritative information
- 2) Decompose the mission space
- 3) Describe simulation elements
- 4) Identify relationships
- 5) Assess and record

1. Collect Authoritative Information

Authoritative information is needed about the application domain that will constitute the simulation context, an important aspect of which is specification of the referent for fidelity and validity assessments. Collection of such authoritative information may involve the use of knowledge engineering techniques – the knowledge acquisition–elicitation–representation processes developed for articulation of rules for expert systems; methods developed for problem formulation in operations research and systems analysis; and other formalisms employed in creating authoritative descriptions of entities, processes, and situations. However, development of the simulation concept and collection of authoritative information for the simulation context are likely to occur iteratively as the entities and processes to be represented become more clearly defined, regardless of the information collection approaches used.

The formal, documented simulation context obtained from authoritative sources is unlikely to address everything needed to fully describe the domain that a simulation is to address. This was illustrated in the CMMS/FDMS endeavors described by Sheehan et al.¹⁷ Those endeavors emphasize a disciplined procedure by which the Developer is systematically informed about the real world and about a set of information standards that simulation SMEs should employ to communicate with and obtain feedback from military operations SMEs. The keys to removing potential ambiguity between the ideas of the military operations SMEs and the simulation SMEs were:

- Common semantics and syntax
- Common format database management system
- Data interchange formats

Experience in the late 1990s with such endeavors showed that information beyond what is likely to be obtained in the first level abstraction (i.e., CMMS/FDMS) may be required for simulation conceptual models, and SMEs may be “called upon to fill in details needed by Developers” that are “not provided in doctrinal and/or authoritative sources”.¹⁸ Clearly, the more completely and clearly stated a simulation context is, the easier it will be to understand where and how one simulation may differ from another in its assumptions about the domain involved. This becomes very important when questions of compatibility among simulations considered for a distributed simulation implementation are addressed. This is further discussed in the section on federation conceptual model development.

Sometimes it becomes obvious that additional information about the simulation context is needed if the simulation is to achieve its objectives (for example, when available information is inadequate, not only when it is not part of the authoritative description of the application domain). This often occurs for simulations used to support new system designs. It may be necessary for test programs to be established to generate such information. Sometimes the missing information consists only of parameter information (the strength of a material or the signal level at which specified levels of distortion occur); other times, the missing information concerns the theory (or algorithms) used to describe entity behavior or performance.

When significant information about critical aspects of a simulation is unknown or uncertain, development of the simulation conceptual model can be more difficult because the set of algorithms and data will be incomplete. Roache¹⁹ provides an excellent discussion of concerns about experimental (test) data, limitations and uncertainties of the data, their generation, and their relationship to simulation V&V. Sometimes inadequate attention is given to potential problems with the quality (correctness and comprehensiveness) of information upon which the simulation conceptual model is based.

2. Decompose the Mission Space

Simulation elements result from decomposition of the mission space which defines the level of granularity or aggregation of the simulation. The basic principles that guide this decomposition are:

Principles for Mission Space Decomposition
1. There should be a specific simulation element for every representation/interaction specified by the simulation requirements.
2. There should be a specific simulation element for every item of potential assessment interest related to the purpose of the simulation.
3. There should be a data source for defined simulation elements. The potential impact of data, and metadata structures, on simulation elements and the simulation conceptual model should not be underestimated.
4. Wherever possible, the simulation elements should correspond to “standard” and widely accepted decomposition paradigms to facilitate acceptance of the simulation conceptual model and effective interaction with other simulation endeavors (including reuse of algorithms or other simulation components).
5. Simulation elements identified for computational considerations (e.g., an approximation used as a surrogate for a more desirable parameter that is not computationally viable) that fail to meet any of the previously stated criteria should be used only when absolutely essential.

To achieve the simulation objectives identified by simulation requirements, the entities and processes that must be represented in the simulation should be identified by the decomposition principles just listed. During this decomposition process, basic decisions are made about the level of detail and aggregation that are appropriate to address simulation requirements. These decisions determine whether a system (a radar, for example) will be represented as a single entity, as a composite of subsystem entities (antenna, transmitter, receiver, etc.), or as a composite of composites of ever smaller entities. Decisions are also made about the level of representation of human decisions and behaviors.

Example

In the movement of a platform (tank, aircraft, ship, etc.), are the decisions and responses of all the people involved (the crew) represented implicitly as a single aspect of the movement control process, or is each person involved represented explicitly (as in a tank simulator with a position for every member of the tank crew)?

3. Describe Simulation Elements

A simulation element is needed for each entity or process (or composites of these) identified during decomposition of the mission space. The basic representational issue is how to describe that simulation element – how to abstract the relevant characteristics. Decisions are made initially about the level of accuracy, precision, and resolution needed in the representation of the entity or process on the basis of the simulation fidelity required. Simulation fidelity is a function of both the scope of representation in a simulation (the entities and processes identified) and the quality of entity and process representation in terms of accuracy, precision, etc. Simulation elements determine functional and behavioral capabilities of the simulation. See [Advanced Topics>Special Topics>Fidelity](#) for additional information.

Representational abstraction is crucial for simulation conceptual model development if the simulation conceptual model is to fully capture all

representational aspects of the situation correctly, but representational abstraction can be difficult to achieve with consistency and thoroughness. Insights from knowledge engineering have been helpful in representational abstraction. Knowledge engineering typically discusses three phases in such abstraction: knowledge acquisition, knowledge elicitation, and knowledge representation. Often three kinds of knowledge structures are identified, each with different acquisition, elicitation, and representation techniques: declarative knowledge (why things work the way they do), procedural knowledge (how to perform a task), and strategic knowledge (the basis for problem solving). Unfortunately, this approach to representational abstraction remains more of an art than a formal unambiguous scientific method. However, representational abstraction has to be arrived at in simulation conceptual model development, and those developing the simulation conceptual model should employ the best methods available to them.

The bottom line is simple: Consistent and comprehensive use of any formalism in simulation conceptual model development is better than the common, *ad hoc*, unstructured approach frequently used.

4. Identify Relationships

The fourth step in the simulation conceptual model development process is to identify all of the relationships among simulation elements (e.g., Sortie Generations Rates on a carrier are impacted by weather, available munitions, and damage to carrier aircraft). This step should ensure that the constraints and boundary conditions imposed by the simulation context, as well as the operational and functional capabilities expressed in the simulation requirements, are accommodated. It also should ensure that the simulation concept is fully articulated.

5. Assess and Record

As the simulation conceptual model is developed, it should be evaluated for clarity, completeness, consistency, and correctness as described in the next subsection. The criteria used to define the level of quality needed, the methods used in the assessment, and the results should be recorded, along with any changes resulting from the assessment. The rationale for changes and the lessons learned from the simulation conceptual model development can provide valuable information for subsequent endeavors.

Simulation Conceptual Model Development Considerations

Two significant aspects of the conceptual model that must be appreciated for efficient and effective development of the simulation conceptual model are *reality abstraction* and *problem identification*.

Reality Abstraction

A simulation conceptual model should be developed within the larger context of simulation theory. The approach to abstracting reality into simulation terms is a key aspect of simulation theory. Without a coherent approach to such abstraction

of reality, different parts of the simulation conceptual model are likely to be incompatible in some way with one another. A number of approaches to simulation theory are available, including Application Domain Modeling²⁰ (such as might be mentioned in SpringerLink's journal of *Formal Methods in System Design*); and the Discrete Event System Simulation methodology developed by Zeigler.^{21,22,23} The larger context of simulation theory can help to ensure that simulation conceptual model development has coherence and can be related more directly to all aspects of simulation development.

Problem Identification

Simulation conceptual model development will often reveal problems with requirements for the simulation, especially if the requirements were not rigorously validated before the start of simulation conceptual model development. As the simulation conceptual model is developed to fully satisfy simulation requirements, inconsistencies among requirements and lack of balance among the requirements (e.g., some very lax and others very stringent in the same general area) may become apparent. Simulation conceptual model development may also reveal gaps in the requirements, i.e., areas where the Developer is left to his own initiative about what the simulation should be able to do. A well-structured simulation development program will encourage (if not insist upon) early, formal, and rigorous validation of simulation requirements and will ensure that requirement deficiencies uncovered during simulation conceptual model development are corrected with appropriate modification to the simulation requirements.

Simulation Conceptual Model Documentation

Guidance and templates for VV&A documentation are provided by DoD MIL-STD-3022.²⁴ The standard addresses planning for and reporting conceptual model validation, but it provides no guidance or template for documenting simulation conceptual model development or the simulation conceptual model itself. The Template for *Simulation Conceptual Model Documentation* discusses both what should be contained in simulation conceptual model documentation and various formats that might be used for simulation conceptual model documentation. See [Resources>Templates>Conceptual Model Documentation](#)

Federation Conceptual Model Description

“Federation” is the HLA term for a collection of simulations working together. The Federation Conceptual Model associated with HLA is defined as:

[A]n abstraction of the real world that serves as a frame of reference for federation development by documenting simulation-neutral views of important entities and their key actions and interactions. The federation conceptual model describes what the federation will represent, the assumptions limiting those representations, and other capabilities needed to satisfy the user's requirements. Federation conceptual models are bridges between the real world, requirements, and design.²⁵

The Distributed Simulation Engineering and Execution Process (DSEEP) endeavors to generalize the systems engineering approach to distributed

simulation embodied in the HLA FEDEP.²⁶ The DSEEP connotation for conceptual model is very similar to that for the HLA FEDEP federation conceptual model:

The conceptual model provides an implementation-independent representation that serves as a vehicle for transforming objectives into functional and behavioral descriptions for system and software designers. The model also provides a crucial traceability link between the stated objectives and the eventual design implementation.²⁶

Thus, conceptual modeling ideas presented in this special topic should apply both to collections of simulations operating within an HLA context and to collections of simulations operating within the more generalized approach represented by the DSEEP. These conceptual modeling comments should also be pertinent to other distributed and large-scale simulations, such as described by Balci and Ormsby,¹⁶ even if they do not comply with the HLA or DSEEP interoperability standards. As a terminology convention for this Special Topic, federation conceptual model will be used to refer to the conceptual model for a simulation (federation) that consists of a collection of simulations (federates) working together, regardless of the standard that may be used to enable interoperability of the simulations. Likewise, the terms federate and federation will be used for individual simulations and groups of simulations, respectively, regardless of whether the simulations are involved in a particular interoperability standard such as HLA.

The “simulation-neutral” and “implementation-independent representation” descriptors in the HLA and DSEEP conceptual model definitions must not be taken in an absolute sense. It may be an objective of the federation to employ specified simulations (federates) or systems within it, which prevents the conceptual model from being absolutely implementation-independent or simulation-neutral. There may be other aspects of the federation objectives that also constrain such neutrality and independence of the conceptual model. For example, every live-virtual-constructive (LVC) exercise is a federation that must function in real time because it involves real systems and real forces. Hence, the federation conceptual model has implementation dependency, i.e., it must function in real time. The purpose of emphasis on implementation independence in the conceptual model definitions is to ensure that the conceptual model leaves the Developer full freedom to design the federation in ways that satisfy federation objectives. It is easy for a conceptual model to preclude various design options if implementation independence is not a goal.

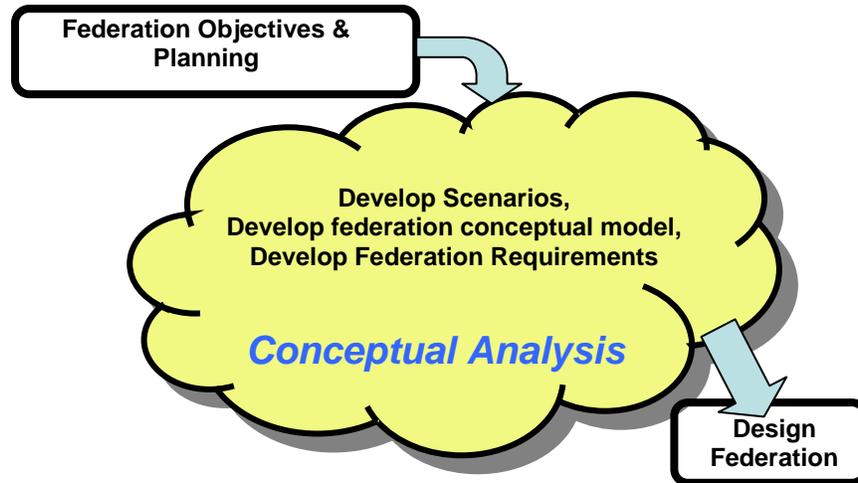
The Distributed Interactive Simulation (DIS) standard for distributed simulations was established prior to HLA and had a slightly different connotation for its conceptual model. The DIS conceptual model is:

[A] statement of the content and internal representations which are the user's and developer's combined concept of the model. It includes logic and algorithms and explicitly recognizes assumptions and limitations.²⁷

DIS did not emphasize a distinct conceptual model for the collection of simulations involved in a DIS exercise. Functions of the Conceptual Analysis Phase and the Design/Development of the Simulation Environment Phase of HLA and DSEEP were addressed in DIS Design, Construct, and Test Exercise activities.²⁸ Hence,

differences between connotation for the DIS conceptual model and the federation conceptual model are sufficiently small that comments about federation conceptual model should be appropriate for the DIS protocol with a collection of simulations.

The figure below provides a simple illustration of the relationship of the federation conceptual model to federation objectives and federation design.



Federation Conceptual Model Development and Related Processes

Sometimes it appears that a simulation conceptual model and a federation conceptual model have different relationships with simulation requirements. As noted earlier, the simulation conceptual model is driven by simulation requirements and leads to the specifications that support a simulation design that will fully satisfy the requirements. In the HLA FEDEP context, the “federation objectives” are like the simulation requirements that drive the simulation conceptual model and “federation requirements” are like the specifications resulting from the simulation conceptual model that drive simulation design. Hence there is no functional difference between the simulation conceptual model and the federation conceptual model even though use of the term “requirements” in slightly different ways could create confusion.

Development and assessment of the federation conceptual model will depend in part upon the way VV&A personnel function in federation development. If VV&A personnel perform all of the tasks indicated by the VV&A overlay to the HLA FEDEP, then some of the things described in this special topic as being done by the federation conceptual model development team will have been done for them by VV&A personnel.²⁵ For example, in Step 1 VV&A personnel both document acceptability criteria for the federation and identify the federation referent. If such things are done by VV&A personnel before federation conceptual model development begins, the federation conceptual model team merely has to include such in the federation conceptual model. The federation conceptual model development team then is saved the effort of developing such itself. This Special Topic identifies what needs to be done in federation conceptual model

development, assessment, and management, but it does not address who should do these things because that can vary with circumstances.

What Does the Federation Conceptual Model Consist of?

In the HLA FEDEP and the DSEEP, the federation conceptual model contains:

- 1) Descriptions of entities and actions that need to be included in the federation in order to satisfy all federation objectives
- 2) An explanatory listing of the assumptions and limitations which bound the model
- 3) Mechanisms to relate federation objectives to federation design

Descriptions of entities and actions should identify static and dynamic relationships between entities and also should identify behavioral and transformational (algorithmic) aspects of each entity. Static relationships can be expressed as ordinary associations or as more specific types of associations such as generalizations (“is-a” relationships) or aggregations (“part-whole” relationships). Dynamic relationships should include (if appropriate) specification of temporally ordered sequences of entity interactions with associated trigger conditions. Entity characteristics (attributes) and interaction descriptors (parameters) may also be identified to the extent possible at this early stage of the process.

Initially the federation conceptual model addresses entities and actions needed by the federation. Only as the federation conceptual model evolves from its initial expression are entities and actions associated with federates that may be encompassed by the federation. Existing conceptual models, especially simulation conceptual models of federates, can provide helpful information and may facilitate identification of assumptions and limitations that result from using different federates in the federation.

Federation agreements also impact the federation conceptual model. How a federation agreement impacts the federation conceptual model depends upon specifics of the agreement. The federation conceptual model transitions through additional enhancement into a reference product suitable to use as a basis for federation design.

If those developing the federation conceptual model are aware of existing simulation object models (SOM) or federation object models (FOM) that map to the intended use, these products may be leveraged in the development of the federation conceptual model. In the past, some thought that SOMs and the FOM would provide adequate conceptual information for an effective federation without the need for a separate federation conceptual model. However, experience has shown that these products focus on the data being passed between the federates and not on the overall description how the representations across the federates would interact.

What Information Should the Federation Conceptual Model Include?

The federation conceptual model begins with understanding federation objectives. At times, development of the federation conceptual model will reveal that federation objectives may need to be modified. For example, performance objectives may be incompatible with resources and schedule. The appropriate authority will have to decide how to accommodate such incompatibilities. In some cases, federation objectives may be modified. In other cases, additional resources and/or schedule increases may be the way the incompatibility is addressed.

Authoritative domain information is employed in the development of the federation conceptual model wherever possible. Such authoritative domain information may come from an authoritative data source related to the application domain.

Federation scenarios are developed in conjunction with the federation conceptual model in the Conceptual Analysis Phase of the FEDEP and the DSEEP. Both the scenarios and the federation conceptual model are to be responsive to federation objectives and to any constraints placed upon the federation, such as those reflected by federation agreements. Constraints include resource and schedule limitations as well as identification of real systems and federates expected to be involved in the federation. Sometimes federation scenarios will be drafted before the federation conceptual model is developed, and other times the federation conceptual model will be developed before federation scenarios are defined. Often federation scenarios and the federation conceptual model will be modified iteratively until an appropriate combination of scenarios and federation conceptual model exists.

Where available, existing conceptual models are an important part of the information included in the federation conceptual model. Such conceptual models, especially those of potential federates, provide insight about entities and their interactions and about assumptions and limitations that may pertain to the federation. Federation conceptual models of federations addressing situations similar or related to the situation that the current federation is to address are also valuable information sources. Existing Simulation Object Models (SOMs) and Federation Object Models (FOMs) that are similar to that which is expected to be developed for the current federation have similar value.

The variety of federation applications within DoD limits the compilation of a prescriptive list of information that should be contained in a federation conceptual model, and neither the HLA FEDEP nor the DSEEP specify the exact information expected in the federation conceptual model. Instead one must infer the kinds of information necessary to support articulation of federation requirements and federation design that depend upon and are derived from the federation conceptual model in both the HLA FEDEP and the DSEEP.^{25,28} Likewise, the federation conceptual model must also contain information to support VV&A processes of the VV&A overlay to the FEDEP.¹² The table below indicates seven categories of information that might be contained in a federation conceptual model.

Sample List of Information Included in a Federation Conceptual Model
Administrative Items
<ol style="list-style-type: none"> 1. Federation identification (e.g., name, version, and date) 2. Format/methodology/tool/technology selected for developing and documenting (describing) the federation conceptual model (and rationale for its selection) and for tracing federation objectives to the federation conceptual model (and subsequently to federation design and implementation) and back to federation objectives 3. Federation conceptual model configuration management method 4. Points of contact for the federation conceptual model (and possibly also for other aspects of the federation, such as its objectives) 5. Federation objectives and constraints (including federation agreements, resource and schedule considerations, acceptable SMEs and other personnel considerations, etc., as well as specification of federation assessment criteria and required tests) with indication of status (approvals, caveats, etc.) of the objectives 6. Federation and federation conceptual model change history (evolution of federation objectives should be part of the change history) 7. Federation conceptual model documentation (with explicit relationship to the federation identification [name, version, and date] and federation conceptual model identification)
Domain-Related Items
<ol style="list-style-type: none"> 1. Authoritative domain information (in whatever form) with indication of the source and pedigree of the information 2. Existing conceptual models (particularly simulation conceptual models of federates that are expected to be involved in the federation and federation conceptual models of previous federations similar to what is expected of this federation) as well as existing SOMs and FOMs related to similar applications 3. Existing scenarios pertinent to federation objectives
Representational Aspects
<ol style="list-style-type: none"> 1. Identification and description of all relevant entities within the domain of interest 2. Identification and description (definition) of both static and dynamic relationships among the identified entities 3. Identification of potential events of interest within the domain, including temporal relationships 4. Thorough identification and description of how states change for entities and how the changes are updated 5. Identification of potential concepts of operation pertinent to the domain and federation objectives 6. Description of and rationale for federation fidelity and performance requirements necessary to satisfy federation objectives 7. Algorithms used to describe entities, their behaviors, and their interactions (sometimes included in the representational aspects and sometimes stated in the assumptions)
Functional Aspects
<ol style="list-style-type: none"> 1. Identification of implementation aspects of the federation required to satisfy federation objectives (LVC simulations; human, hardware, software, system in the loop elements; security considerations; federation agreements; time management and federation execution management capabilities needed to satisfy federation objectives; computational capabilities [hardware, software, architecture, protocol, etc.] necessary to satisfy federation objectives; etc.) 2. Information products (simulation outputs and intermediate parameter values, etc.) necessary to satisfy federation evaluation objectives and fully support federation VV&A

Sample List of Information Included in a Federation Conceptual Model (continued)
Assumptions and Limitations
<ol style="list-style-type: none"> 1. Identification of assumptions at both federate level and federation level, with explicit notice of incompatibilities and inconsistencies among the assumptions (federate simulation conceptual models should be an important source of assumptions about the federates) 2. Explicit discussion of implications for assumptions in regard to federation objectives and indications of stakeholder responses to such implications 3. Identification of limitations at both federate level and federation level (federate simulation conceptual models should be an important source of limitations about the federates) 4. Explicit discussion of implications for limitations in regard to federation objectives and indications of stakeholder responses to such implications
V&V History (mainly pointers to documents and information sources)
<ol style="list-style-type: none"> 1. Assessment(s) of federation objectives 2. VV&A of federates considered for the federation 3. V&V of any existing conceptual models or scenarios used in federation conceptual model development 4. V&V/IV&V applied to the federation conceptual model or to the federation when reuse of the federation with or without modification is considered. It is important that the federation conceptual model be thoroughly assessed (verified and validated) before use as the basis for federation requirements and subsequently to support development of federation design
Summary
<ol style="list-style-type: none"> 1. Synopsis of federation conceptual model capability to support federation objectives with explicit indication of which objectives might not be fully satisfied and why 2. Brief description of federation conceptual model capabilities and attributes (usually in presentation form), intended to ensure that all interested parties (stakeholders, User, sponsor, Developer, SMEs, other consumers of federation results, etc.) have a common appreciation for and understanding of the federation conceptual model 3. Federation conceptual model maintenance and additional federation conceptual model development plans

What Can a Federation Conceptual Model Do?

Like the simulation conceptual model, the federation conceptual model has two primary functions, to facilitate federation development and to facilitate federation assessment.

- The federation conceptual model facilitates federation development by providing a mechanism through which all interested parties can acquire a common understanding of how federation objectives can be transformed into something that system and software designers can implement. In both the HLA FEDEP and the DSEEP, the federation conceptual model is involved in federation scenario development. The federation conceptual model and federation scenarios together with federation objectives and constraints are the basis for federation requirements, upon which a federation design will be developed.
- The federation conceptual model facilitates federation assessment by providing a logical basis for judgments of simulation performance in the early phases of federation development when federation results do not yet exist and at the implementation phase where a sufficient validation referent may not exist.

How Can a Federation Conceptual Model Be Used?

The federation conceptual model or information from it serves as an input to development of federation scenarios and federation requirements, and it supports development of the federation design. In the HLA FEDEP, the federation conceptual model also is an input to development of the FOM and supports development of federation agreements. In the DSEEP, the federation conceptual model has similar functions, even though the DSEEP does not use the same terminology or exactly the same processes used by the HLA FEDEP. The federation conceptual model is directly involved in federation VV&A¹² and can support federation test and evaluation.²⁸

Where Can a Federation Conceptual Model Be Found?

In the HLA FEDEP and the DSEEP, the federation conceptual model when assessed and completed becomes a “reference product suitable for federation design”²⁸ and should be available among federation products and artifacts. In general, for federations that develop a distinct federation conceptual model, such as is done in the HLA FEDEP and the DSEEP, the federation conceptual model will be among the reference products and other important items of federation development. For collections of simulations working together that do not emphasize a distinct conceptual model (as was the case in some DIS exercises), the information of which the conceptual model consists may be scattered among various documents and other artifacts. In such cases, it may be impossible to reconstruct a complete and coherent federation conceptual model for that collection of simulations.

What Does a Federation Conceptual Model Look Like?

The wide variety of federation applications in DoD and the variety of conceptual model development and documentation methodologies cause great variety in how federation conceptual models look. A federation conceptual model developed mainly in a UML construct, such as in the Synthetic Environment Specification Tool-set for which “federation conceptual model is the centerpiece”²⁹ or as described by Tanriover and Bilgen,³⁰ will look quite different from those developed using Department of Defense Architecture Framework (DoDAF) methods,³¹ the knowledge engineering methodology emphasized in DCMF,¹⁰ or formal specification such as described by Brade.³²

While some suggest that it is desirable for the federation conceptual model to be documented mainly in one format, many federation conceptual models are likely to employ a number of formats for their development and documentation. For example, the authoritative domain information may come mainly in knowledge engineering formats, because that is the approach some data producers use. Representational aspects of the federation conceptual model may be documented in one of the UML-related formats, because many find this to be a convenient way to ensure that those developing software for the federation correctly understand what is desired. Functional aspects of the federation as well as its assumptions and limitations may be best documented in scientific paper or report format so that

they are most fully described in a manner easily understood by anyone with technical competence. Thus, it is easy to understand why a federation conceptual model might employ multiple formats in its development and documentation.

The most important characteristics of the format(s) used in federation conceptual model development and documentation are clarity and completeness so that all needed information is contained and the information is most readily understandable for the federation's collection of interested parties (sponsor, User, SMEs, Developer personnel, stakeholders, VV&A personnel, etc.).

Federation Conceptual Model Development

Federation Conceptual Model development is impacted by the development process employed. In both the HLA FEDEP and the DSEEP, "Perform Conceptual Analysis" is the second step in the defined development process. That step involves three activities: Develop Scenario, Develop Conceptual Model, and Develop Federation Requirements (HLA FEDEP/DSEEP). Within the HLA FEDEP, both scenario development and federation conceptual model development are driven by authoritative domain information. Regardless of the specific reference to HLA, this section should be generally applicable to any distributed simulation standard.

Federation Conceptual Model Development Process

As noted earlier, sometimes a federation conceptual model will be developed before the scenario and sometimes the scenario will be developed first. In many, perhaps most, situations, the scenario and federation conceptual model will be developed in parallel with many interactions between them, iteratively revising and updating as appropriate until a combination of scenario and federation conceptual model comes into being that can stimulate a set of requirements that fully satisfy the federation objectives.

The federation conceptual model develops as the federation conceptual model team produces a conceptual representation of the intended problem space on the basis of their interpretation of User needs and federation objectives. Early in federation conceptual model development, the focus is upon identification of relevant entities, the static and dynamic relationships among entities, and the behavioral and transformational (algorithmic) aspects of each entity within the domain of interest, which is defined by the scenario (or set of scenarios). As noted in both the HLA FEDEP and the DSEEP, the scenario "provides a bounding mechanism for conceptual modeling activities."

The FEDEP and the DSEEP identify four inputs for developing a federation conceptual model:

- 1) Federation objectives
- 2) Authoritative domain information
- 3) Existing scenarios and the federation scenario being developed (although as noted earlier, development of the scenario may be done in parallel with federation conceptual model development)

- 4) Existing conceptual models (this might include federation conceptual models for similar federations, simulation conceptual models from simulations that might become federates of the federation, FOMs and SOMs from similar applications, and conceptual models related to the domain of interest or data sources)

The FEDEP recommends six tasks for developing the federation conceptual model (which are very similar to the five steps for simulation conceptual model development). The steps for federation conceptual model development are:

- 1) Choose the technique and format for development and documentation of the federation conceptual model.
- 2) Identify and describe all relevant entities within the domain of interest.
- 3) Define static and dynamic relationships between federation entities.
- 4) Identify events of interest within the domain, including temporal relationships.
- 5) Document the federation conceptual model and related decisions.
- 6) Working with federation stakeholders, verify the contents of the conceptual model.

The DSEEP segregates the task to “[C]apture applicable concept of operations in the conceptual model” after step 4 in the FEDEP tasks.

Federation conceptual model development is also expected to provide a mechanism for tracing federation objectives through the federation conceptual model to federation requirements and then to federation design and implementation.

Federation Conceptual Model Development Considerations

Federation objectives

Often federation conceptual model development will reveal problems in federation objectives. The objectives may be inconsistent with resources or schedule. Ideally such problems will be identified and corrected in first step of the FEDEP or the DSEEP, which includes federation objective definition and initial planning. Unfortunately such problems are not always identified and corrected before the start of federation conceptual model development. Consequently the federation conceptual model development team may have to turn to the authorities (and stakeholders) who produced the federation objectives for clarification or correction of the objectives. It is never wise to develop a federation conceptual model upon objectives having known problems. It is always helpful when the objectives include all constraints placed upon the federation (such as specification of federates to be included; identification of tools and techniques to be used in federation development, management, or use; specification of evaluation criteria or required tests; federation agreements; etc.).

Authoritative domain information

It is always helpful to have authoritative domain information, especially if it is in formats that permit it to be used without transformation. However, it is unlikely that the authoritative domain information will contain all the information needed for the federation conceptual model. The challenges for the federation conceptual model development team are to recognize where there are gaps in the authoritative domain information and to fill in those gaps appropriately. At times it may even be necessary to ignore authoritative domain information because its context or assumptions are incompatible with what the federation is to do.

Selection of the technique and format for developing and documenting the federation conceptual model

As noted earlier, it may be necessary to use more than one technique and format to develop and document the federation conceptual model. Whether a single technique and format are used or multiple techniques and formats are used, it is important that the federation conceptual model be complete, consistent, and clear. These attributes are discussed in more detail below, under federation conceptual model assessment.

Identification and description of domain entities, behaviors, interactions, events, and processes

This decomposition of the federation mission space includes concepts of operation as well as the physical phenomena and their temporal relationships that could occur within the application domain. One of the challenges in federation conceptual model development is determination of the level of resolution and fidelity required for entities and processes in the federation conceptual model such that federation requirements derived from the federation conceptual model elicit a federation design that can fully satisfy federation objectives. Documenting the rationale for federation conceptual model resolution and fidelity is very important.

Federation Conceptual Model Documentation

Guidance and templates for VV&A documentation are provided by DoD MIL-STD 3022.²⁴ The standard addresses planning for and reporting conceptual model validation, but it provides no guidance or template for documenting federation conceptual model development or the federation conceptual model itself.

Using Existing Conceptual Models

When a legacy simulation is being modified for use as a standalone simulation or as a federate, its existing simulation conceptual model may be incorporated into the conceptual model for the simulation under development. Before such a conceptual model can be used, its quality should be assessed to ensure that it is appropriate and sufficient. Conceptual model quality assessment addresses how well the simulation conceptual model will support simulation development.

Conceptual model quality is assessed by examining the conceptual model's adequacy in representing the legacy simulation, its implementation independence, and the availability of its documentation. When assessing the ability of a conceptual model to support simulation development, adequacy is a function of three factors: completeness (scope), depth (level of detail), and accuracy. Completeness and depth are mainly concerned with whether the conceptual model properly represents the simulation; accuracy is mainly concerned with whether the conceptual model can support the intended use.

- 1) **Completeness** – The conceptual model documentation should be reviewed to confirm that all representational aspects, functional aspects, constraints, assumptions, and limitations are reported.
- 2) **Depth (level of detail)** – Depth relates to the resolution with which entities in the conceptual model reflect the real world. The conceptual model should contain enough detailed information to support assessment of all federation objectives or simulation intended uses. Further, all the relevant functional characteristics of entities should be included such that there are no gaps when the V&V agent tries to verify an objective relative to an entity.
- 3) **Accuracy** – Conceptual model accuracy relates to how well the conceptual model reflects the real world being modeled or simulated and whether this representation is appropriate (adequate) for federation objectives or the simulation's intended use.

Example

If small acceleration errors are important in the federation's applications, using a constant for gravity probably would not produce acceptable results from the simulation.

The conceptual model may have been developed and/or modified to address an intended use different from that for the simulation under development. The conceptual model of a legacy simulation may also represent a different version of the simulation.

Informal assessment techniques, such as face validation, reviews, or walkthroughs, are often used to assess conceptual model completeness, depth, and accuracy.

Conceptual Model Management

Conceptual model management should be embedded in the overall management process for the simulation as much as is reasonable. For example, conceptual model configuration management (distinct identifier for each version; version review and approval processes) should be accomplished as part of the configuration management process being employed. The HLA FEDEP and the

DSEEP are very clear about where federation conceptual model development fits in the federation life cycle and both processes stipulate that configuration management should be addressed in initial planning for the federation; however, neither is clear about whether the federation conceptual model is expected to be addressed by the federation's configuration management system.

Conceptual model development and management should be considered normal project activities and all standard project management considerations should pertain (cost, schedule, personnel, milestones, deliverables, pertinent standards, organizational guidance, etc.). Progress and problems encountered should be noted and addressed appropriately.

The function of conceptual model management is to ensure that:

- Each conceptual model version (and in some cases even a portion of the conceptual model) is uniquely identified and readily available to everyone involved in simulation development, assessment, and/or use (subject to restrictions for security, need-to-know, etc.)
- Appropriate information is available to support conceptual model quality assessment and conceptual model validation
- Information pertinent to conceptual model development (requirements, referent information, etc.) can be located as needed

Conceptual model management should also address establishment of a repository of conceptual model development artifacts (briefings, reports, etc., related to the conceptual model) and help with the management of SMEs and others used in the development and review of federation conceptual model materials.

Within DoD, a federation may involve federates located in widely distributed geographic locations, and may even involve multiple interoperability standards. This often is the situation in LVC exercises, such as those described by Hudgins et al.³³ The management issues resulting from the multiple organizations involved in the federation and from compliance issues related to the various protocols and standards (including gateways and middleware) related to them tend to be more complex than issues encountered with a simulation conceptual model, even for large and complex simulations.

Documentation Availability

A conceptual model should be documented, and that documentation should be readily available to everyone involved in simulation development (User, Developer and simulation development personnel, sponsor, SMEs, VV&A personnel, etc.). The final federation conceptual model documentation should always be readily available in a federation developed according to the HLA FEDEP or the DSEEP, since the federation conceptual model is considered a "reference" product suitable to serve as a primary basis for federation design. An effective configuration management process that is applied to the conceptual model in addition to other simulation development products prevents adverse situations from occurring, such as loss of an earlier version of the conceptual model that documents the

assumptions and rationale for entity selection. Further, such documentation might be useful to support federation VV&A planning.

In many simulation development paradigms, conceptual model development precedes development of simulation design. However, this is does not always occur in practice. Sometimes the conceptual model is created first; sometimes the simulation design is begun before the conceptual model is completed. Sometimes the conceptual model is not developed until it is needed for simulation validation. The earlier that descriptions of simulation elements are available, the better, because valuable feedback from simulation conceptual model assessment or conceptual model validation can identify problems and circumvent faults in simulation design and implementation. The importance of this principle is illustrated by the frequency with which serious problems are found during conceptual model validation reviews.

Conceptual Model Assessment

Conceptual model verification is a review of the conceptual model with respect to the federation objectives or simulation requirements. Conceptual model validation is a review of the model with respect to the referent.

Conceptual Model Verification

The VV&A overlay to the FEDEP defines conceptual model verification as follows:

This activity verifies the internal consistency, completeness, and correctness of the Federation Conceptual Model and its consistency with the verified Federation Objectives and the Federation Scenarios. This step assures that the representations defined in the Federation Conceptual Model are internally sound and can support the execution of the Federation Scenarios. This creates a firm foundation for conceptual model validation and the derivation of the Federation Requirements.¹²

This definition can also be applied to verification of conceptual models of both federations and standalone simulations.

Federation Conceptual Model Verification

Federation conceptual model verification has two basic functions:

- To ensure that the federation conceptual model is responsive to *all* federation objectives
- To ensure that the federation conceptual model is responsive to *all* pertinent entities, processes, interactions, and events of the application domain.

Obtaining concurrence from the authorities (stakeholders) who established federation objectives is both a good sanity check for the federation conceptual model development team and confirmation that the federation conceptual model has achieved those aspects of its functions. Conceptual model validation will take

the next step and address appropriateness of fidelity that could be expected from a federation design based upon the federation conceptual model.

Simulation Conceptual Model Verification

As with federation conceptual models, simulation conceptual model verification has two basic functions:

- To ensure that the conceptual model is responsive to all simulation requirements or federation objectives, as appropriate.
- To ensure that the conceptual model is responsive to all pertinent entities, processes, and interactions of the application domain.

Consistency

Consistency is concerned with the relationship of “parts” of the conceptual model to one another. That is, do the parts work in harmony or do they have potential to produce inconsistent effects in simulation behavior? This is a particular concern for distributed simulations, because some potential federates may not be compatible. For example, in LVC exercises, sometimes performance of simulated sensors has been too good, much better than the performance of the real sensors in the exercise.

It is also a concern because algorithms or representations may be drawn from various sources; sometimes they are based upon incompatible assumptions and procedures. A conceptual model has adequate consistency if the assumptions, algorithms, and representations of its parts are not incompatible. Special care should be used when algorithms are taken from more than one source to ensure that those sources do not employ contradictory assumptions or factors (different models for the shape of the earth, different characteristics of the environment, different assumptions about flow through a network such as steady-state or otherwise, etc.).

Completeness (Scope)

Completeness refers to the conceptual model’s breadth of coverage of the simulation (federation objectives and the application domain).

- If any requirement for the simulation is not reflected in the simulation conceptual model, it is not complete.
- If any representational element or simulation capability of a legacy simulation is not included in the simulation conceptual model, it is not complete.
- If any federation objective is not reflected in the federation conceptual model, it is not complete.
- If any entity, interactions among entities, or process in the application domain involved in any federation objective is not reflected in the federation conceptual model, it is not complete.

Only a complete conceptual model should be considered adequate.

The mechanism for tracing federation objectives (or simulation intended uses) to the conceptual model and then to simulation requirements is an important facet of conceptual model verification. The tracing mechanism can also be used to trace application domain entities, processes, and interactions into the conceptual model and simulation requirements. The tracing mechanism will help to identify any aspects of the conceptual model that are not responsive to federation objectives (or simulation intended uses) or derived from the application domain. Such aspects normally have no legitimate place in the conceptual model.

DoD MIL-STD-3022 for documenting M&S VV&A does not specifically address conceptual model verification, although conceptual model verification is implied by statements about design verification linking the design to the conceptual model and the federation objectives/simulation requirements traceability matrix. The exact process and reporting used for federation conceptual model verification can be tailored to the particular situation in accordance with the VV&A overlay to the FEDEP¹² without any particular compliance considerations based upon guidance from outside the federation project.

Each of the federation objectives and constraints (or simulation intended uses) should have a unique identifier. This is essential for tracing federation objectives and constraints (or simulation intended uses) to the conceptual model and then to simulation requirements. If such identifiers do not exist, those performing the conceptual model verification should generate them. Likewise, unique identifiers for application domain entities, processes, and interactions are needed for tracing them to the conceptual model. An entity has a collection of attributes and characteristics (parameters) that are used in the algorithms that describe the entity, its behavior, and interactions with other entities. The tracing mechanism should facilitate checking that all pertinent aspects of the application domain are reflected in the conceptual model. Appropriateness of how pertinent aspects of the application domain are treated in the conceptual model is not part of conceptual model verification; rather that subject is addressed in conceptual model validation.

Correctness

Correctness refers to the implementation of the requirements and objectives and to the accuracy of the representation relative to the referent.

Verification Report

Conceptual model verification reporting should address the five main topics shown below:

- 1) **Representation of federation objectives and constraints or simulation intended uses** – Every federation objective or simulation intended use represented in the conceptual model should be identified. The VV&A overlay to the FEDEP makes the point that federation objectives should have been previously verified so that federation conceptual model development can begin on a sure foundation.

- 2) **Representation of application domain entities, processes, and interactions** – Every aspect of the application domain represented in the conceptual model should be identified.
- 3) **Limitations** – This section identifies the federation objective and/or intended use as well as all pertinent application domain characteristics not represented in the conceptual model. A comment should be made about each limitation identified that explains why the item is not represented and what plans may exist to remove the limitation. Such plans might include something like (a) the next version of the conceptual model is expected to remove this limitation by introducing an additional algorithm that will reflect the federation objective or application domain characteristic, or (b) it has been suggested that the federation objective be modified or removed, and User response to the suggestion has not yet been received.
- 4) **Extraneous items** – A comment should be made about every aspect of the conceptual model which is neither responsive to one of the federation objectives or simulation intended uses nor to an aspect of the application domain. The comment should explain what the extraneous item is and why the conceptual model development team has included it.
- 5) **Conclusion** – This portion of the conceptual model verification report should indicate whether the conceptual model limitations and extraneous items are considered so significantly deleterious that major revisions to conceptual model development plans are needed. Caveats about use of the conceptual model until such problems are corrected are always appropriate. If a conceptual model verification review is performed on an intermediate version of the conceptual model, it may be appropriate to recommend that simulation design not commence on the basis of that version of the conceptual model but to wait until a more mature version of the conceptual model exists.

If aspects of the conceptual model are listed in the tracing mechanism with indications of which simulation requirement or application domain characteristic they address, then the first two information items in the conceptual model verification report can be generated automatically by the tracing mechanism. Likewise, identification of entries in the conceptual model verification report of the third and fourth information items can also be generated automatically by the tracing mechanism. Only the comment portion will require additional work.

Because conceptual model verification review is less subject to analytic interpretation than conceptual model validation, vested interest concerns about personnel involved in conceptual model verification review are less an issue than they might be in conceptual model validation review. It is expected that the federation conceptual model verification review will be staffed by VV&A personnel, Developer personnel involved with conceptual model development, SMEs, or some combination of the three. VV&A planning should include resources for conceptual model verification and include time in the conceptual model development schedule to accommodate it.

Conceptual Model Validation

The VV&A overlay to the FEDEP notes that the federation conceptual model “provides the first meaningful insight into the federation’s validity.”¹²

Conceptual model validation is performed when a simulation has not been tested by direct comparison of simulation results with an appropriate referent. One would not expect simulation design to commence until the conceptual model had been successfully validated. The ability of the VV&A team to perform conceptual model validation tasks depends upon information in the federation objectives (or intended simulation uses) and specified evaluation criteria such as the Acceptability Criteria, the information in the conceptual model, and resources available for the conceptual model validation. In some situations, conceptual model validation might be based upon simulation design instead of the conceptual model. That might make conceptual model validation more difficult, since some of the information (such as assumptions) might not be as available in simulation design materials.

Conceptual model verification supports conceptual model validation by providing evidence of conceptual model compliance with federation objectives or simulation intended uses.

After a simulation has been built and results from it are available, conceptual model validation can be used to supplement results validation (i.e., comparison of simulation results with the referent or SME review) by providing insights about simulation behavior under conditions not directly addressed in the referent or the SME review. ***It is very important to understand that conceptual model validation is involved both in supporting simulation development and in assessing appropriateness of simulation applications after development has been completed.***

Conceptual model validation is normally based on SME review. Reviews are performed on parts of the conceptual model (e.g., individual entities and processes, interactions among entities, and information about the application domain) using SME expert opinion. Quantitative assessments such as sensitivity analyses and comparisons with data from various sources may also be employed in the review. These reviews are accumulated and combined. SME use in conceptual model validation should conform to best practices for using SMEs to increase confidence in the assessment and to increase the repeatability of the assessment. Perspective about conceptual model validation is provided below.

- Conceptual model validation is performed on a federation conceptual model part to determine the fitness of the representation of that item in the federation relative to federation objectives.
- Conceptual model validation is performed on the federation conceptual model overall to assess the overall capability of the federation if federation design is based upon the federation conceptual model.
- Conceptual model validation is performed on information about the application domain and any constraints of the federation objectives to

assess the appropriateness of the constraints and boundary conditions imposed upon capability of the federation relative to federation objectives.

Conceptual model validation reviews serve as the basis for judging federation capabilities for conditions other than those specifically tested or validated by comparison of federation results with referent information. This makes conceptual model validation extremely important because, in a large or complex federation, results validation and testing can only address a small part of federation capabilities under a limited set of circumstances. Additional information about validation may be found in the VV&A overlay to the FEDEP¹² and [Advanced Topics>Special Topics>Validation](#).

The VV&A overlay to the FEDEP¹² notes that conceptual model validation assumes the existence of a completed and verified federation conceptual model, federation Acceptability Criteria (and by implication federation objectives), federation referent, and federation V&V plans. Sometimes conceptual model validation may commence on federation conceptual model parts before all of the information noted above is available.

The VV&A overlay to the FEDEP¹² identifies four tasks associated with conceptual model validation:

- 1) Evaluate the completeness of the federation conceptual model against the federation acceptability criteria and federation referent, and identify areas of incompleteness.
- 2) Where possible, estimate the error characteristics of the federation conceptual model.
- 3) Evaluate the correctness of the federation conceptual model against the federation acceptability criteria and federation referent, and identify areas of incorrectness. Where possible, document the federation conceptual model validation results.
- 4) Support reviewing the contents of the federation conceptual model with the User/sponsor.

All of these tasks are included in the processes described below for conceptual model validation.

Conceptual Model Validation Review Fundamentals

The following generally apply to conceptual model validation reviews.

1. Review scope and criteria

Conceptual model validation helps determine federation capability to satisfy federation objectives. For new and modified federations, conceptual model validation also helps determine if adequate information is available to fully support federation development or modification from the perspective of federation objectives. Conceptual model validation reviews are best able to ensure federation correctness and enhance federation credibility when the scope of a review and the criteria used in the assessment are stated explicitly and defined before the

conceptual model validation review commences. The review process works most smoothly when the review scope and evaluation criteria are agreed to by the User/sponsor and the Developer as well as by reviewers.

2. Review format

All reviews related to a particular federation should use similar reporting formats, and where possible use reporting formats that are compatible with reviews of other federations applied to the same kind of application. Guidance and templates now available in the DoD standard for M&S VV&A documentation²⁴ make this easier than was the case previously. Reports of conceptual model validation reviews should include information and rationales as well as conclusions. Conceptual model validation evaluations should always be performed within the context of expected federation application, i.e., within the context of federation objectives.

3. Review scheduling

Scheduling conceptual model validation reviews depends upon several factors. First, description of the federation conceptual model must exist. In the past, some federation developments did not require distinct and complete federation conceptual model documentation (e.g., DIS exercises). This severely hampered conceptual model validation reviews of those federations, postponing the discovery of federation problems that could have been discovered earlier in federation development until they manifested themselves in federation use. This can be very costly.

Depending upon the federation development paradigm used, a “final” and full federation conceptual model may be available prior to high-level or detailed design for a new or modified federation. However, sometimes the final (full) federation conceptual model description may not be available until after design and implementation have begun. Preliminary conceptual model validation reviews can be performed on a partial and preliminary federation conceptual model. While this kind of conceptual model validation review can help to detect ideas that will cause federation faults, conceptual model validation of a preliminary conceptual model should never be used as a basis for evaluation or assessment of the federation, because only the final federation conceptual model can be the basis for that judgment. When validation review resources are limited (as usually is the case), they must be used with discretion to ensure both that a sound basis exists for judgment about federation suitability (i.e., conceptual model validation based on the final federation conceptual model) and that federation development also benefits from as much early conceptual model validation review as resources allow.

A second factor affecting the timing of conceptual model validation reviews is availability of appropriate reviewers. Often an appropriate administrative structure through which conceptual model validation review personnel, especially SMEs who are outside the federation development team, can be engaged does not exist until well along in federation development. Typically this lack of appropriate administrative structure prevents timely verification review of federation objectives, with the consequence that the federation development contract may be issued

based upon faulty information, which can have major cost implications for federation development. Lack of early V&V input may have similar results.

Resource limitations for conceptual model validation reviews may restrict the review to only the final version of the federation conceptual model, and in many cases, will even restrict the review so that only the more critical parts of the federation conceptual model are reviewed. Because of this, it is very important that experienced VV&A personnel be sought to provide advice about how to accomplish as much as possible of the required conceptual model validation within the available resources. This is the normal situation – that one cannot do as much V&V as desired or, in some cases, as required to reduce the risk of a federation that is not fully able to satisfy federation objectives being accepted to support those objectives.

Example

The simulation development contract may fail to require that distinct documentation of the simulation conceptual model be provided in a timely fashion, and instead it leaves the simulation conceptual model to be deduced from simulation design documentation such as the software development document and the detailed software development requirements document. This can be an even more significant problem if the design documents are not done well or do not consistently identify assumptions and sources, etc., associated with items in the documents.

Conceptual Model Validation Process

Conceptual model validation reviews have a primary purpose of determining federation appropriateness for its intended use (i.e., its capacity to fully satisfy federation objectives) and two related secondary purposes: to increase federation correctness and to enhance federation credibility. To enhance federation credibility normally requires that conceptual model validation reviews be performed (at least in part) by those outside the federation development team, and it may require that the conceptual model validation review team include everyone with vested interests in the federation.

1. Establish conceptual model validation review scope and assessment criteria

Ideally the scope of conceptual model validation would include everything, but in practice the scope of conceptual model validation is often restricted to the more significant aspects of the federation. Assessment criteria come in two flavors. The first concerns the capability of the federation conceptual model to support federation objectives and is part of the general V&V of the federation (e.g., part of the VV&A overlay for the HLA FEDEP for HLA federations). This defines the expected validity of the federation conceptual model for applications that the federation was designed to address. The second concerns the capability of the federation conceptual model to support a particular application of the federation and is oriented toward support of an accreditation decision. This may require conceptual model validation review for each particular application, as shown in the example below.

Example

A federation may be intended to have the capability to represent many different kinds of weapon systems, but a particular application of the federation is only going to address a limited set of weapon types. The first set of assessment criteria would cover all weapon types that the federation is to be capable of representing, and the second set would only cover weapon types of the intended use. However, it may be necessary to perform a conceptual model validation review for each particular application, especially if an application introduced stringent demands or unusual circumstances. If a missile defense simulation needs to evaluate new guidance approaches for the interceptor, a new conceptual model validation may be necessary to determine if algorithms in the federation conceptual model can support those approaches to interceptor guidance adequately. Material from previous conceptual model validations can reduce the effort required to perform new or additional conceptual model validations.

Establishing the scope of the conceptual model validation review and the assessment criteria must be done authoritatively. The User/sponsor must issue the document that establishes the conceptual model validation review scope and the assessment criteria; otherwise the federation application (whether legacy or new or modified development) may not be responsive to findings of the review. Normally the contents of this document will have been drafted by an element of the V&V or independent V&V (IV&V) team for the simulation and will incorporate Developer perspectives appropriately before submission to the User/sponsor for approval. This issue is addressed explicitly in the VV&A overlay for FEDEP¹² by development of Federation Acceptability Criteria in Step 1 of the FEDEP.

2. Identify and orient review personnel

Normally conceptual model validation reviews are performed by a VV&A team. That team may include some who are not considered VV&A personnel. The subject matter determines the required technical expertise. Vested interests (e.g., interests of a program office whose system is to be represented in the federation) also impact who should be included in the conceptual model validation review team. An ideal situation would have a review team that both represented all parties with vested interests and contained other qualified SMEs (who have no vested interest) for objectivity. Some federation developments use a formal SME nomination/application form (somewhat similar to a resume) to capture relevant information about prospective conceptual model validation SMEs in a structured and common format. This helps to limit criticism about SME appropriateness when the reviews uncover problems (or fail to uncover perceived potential problems). Normally SMEs who are not part of federation development personnel need orientation about the federation, its intended uses, the criteria for their review and assessment, and, in some cases, the descriptive format for the federation conceptual model (as when a design accommodation method for describing the federation conceptual model is employed).

3. Develop conceptual model validation review process

Developing the conceptual model validation review process involves determining how the review will be conducted (via documents only; from documents supplemented by some interaction with the federation development team; mainly

by interactive dialogue between the reviewer(s) and the federation development team; by experiments with a legacy code to help deduce its underlying federation conceptual model; etc.) and how the review will be reported. Obviously the conceptual model validation review will need to be reported in accord with pertinent guidance, such as the VV&A overlay for FEDEP¹² or MIL-STD-3022,²⁴ but a variety of report structures and formats are compatible with this guidance. The review process discussed here concerns selection of the specific report structure and format to be used. A structured review report form helps to ensure consistency, comprehensiveness, and comparability for reviews of different parts of a federation conceptual model when a variety of review personnel are used. The conceptual model validation review process also includes how the description of the federation conceptual model is collected (if a distinct documented federation conceptual model does not exist) and passed to review personnel, arrangement of meetings to support the review process, managing the reports and other documents, etc.

4. Conduct conceptual model validation reviews

Conducting a conceptual model validation review involves scheduling review personnel (members of the VV&A team and federation development team supporting conceptual model validation reviews, as well as SMEs and others from outside the federation development team), getting appropriate materials (federation conceptual model description, review orientation and report forms) to those involved, monitoring review processes, collecting reports from the reviewers, etc. Conceptual model validation of a major federation may require reviews of all major systems represented by the federation as well as reviews of the overall federation addressed by the federation conceptual model. Sometimes multiple reviews are conducted to accommodate all vested interests. Including adequate resources in V&V planning for both administration and performance of conceptual model validation reviews is essential. It is wise to begin with reviews of the more critical parts of the federation conceptual model so that adequate time and attention will be given to the more important aspects of the conceptual model validation review.

5. Submit conceptual model validation review results for response

The Developer or the User/sponsor (or both) may have a different perspective about the federation than that resulting from the initial conceptual model validation review of the federation conceptual model. It is wise to provide an opportunity for the Developer and the User/sponsor) to respond to the review before it is finalized. Sometimes a misunderstanding reported by the review has to be corrected. Sometimes a fault is identified (when conceptual model validation is performed for an existing federation) and the Developer devises (and implements) a way to correct it. The purpose of this kind of iteration between the reviewers and the Developer and User/sponsor) is to eliminate unnecessary differences about the conceptual model validation reviews and to make sure that final versions of the reviews reflect the most recent situation (such as the faults corrected).

6. Synthesize conceptual model validation reviews and draw conclusions

Multiple conceptual model validation reviews of the same federation conceptual model item (such as an entity, process, or interaction) are consolidated and conclusions drawn about that federation conceptual model item. In addition, conceptual model validation reviews of all parts of the federation and of the federation conceptual model are assimilated and conclusions are drawn about the federation conceptual model and about the federation overall. Typically this synthesis of all materials from the conceptual model validation review is performed by the leader of the conceptual model validation effort for the simulation.

Conceptual Model Validation Report

The types of information that should be included in a conceptual model validation report are listed in the table below.

Types of Information Needed In Conceptual Model Validation Report
<ul style="list-style-type: none"> • Identification of the federation conceptual model (or the part of it) being reviewed – by name, version, date, etc., of the federation conceptual model when such information exists
<ul style="list-style-type: none"> • Review personnel (names, contact information, areas of expertise, etc.)
<ul style="list-style-type: none"> • Information used during review: documents, interactions with development team members by name and date, results from simulation runs, etc.
<ul style="list-style-type: none"> • Scope and criteria for representational assessment employed in the review
<ul style="list-style-type: none"> • Explicit representational enumeration: <ul style="list-style-type: none"> – Are all elements and aspects of the item (entities, states, behaviors, actions, tasks, etc.) to be represented included? – If not, which ones were omitted? – Are those omitted pertinent for intended federation applications?
<ul style="list-style-type: none"> • Assessment of assumptions pertaining to conceptual model or the part being reviewed: <ul style="list-style-type: none"> – Are all assumptions identified? – Are implications of these assumptions clearly and correctly identified? – What assumptions were omitted and what implications need clarification?
<ul style="list-style-type: none"> • Assessment of algorithms used: <ul style="list-style-type: none"> – Do the algorithms provide adequate fidelity (as expressed in terms of accuracy, resolution, etc.) for the federation to support the intended uses, to satisfy federation objectives fully, and to comply with criteria given as guidance for the conceptual model validation review? – Are the algorithms correct, appropriate, with acceptable and authoritative pedigrees? – What is the relation of these algorithms to “standard” algorithms used elsewhere within the Defense community?
<ul style="list-style-type: none"> • Conclusion and synopsis of conceptual model validation review findings, clearly separating fact from interpretation and explaining the significance of the findings
<ul style="list-style-type: none"> • Recommendations for improving simulation correctness or credibility or future federation conceptual model validation review processes

Normally conclusions from conceptual model validation review need to be endorsed or accepted by the User/sponsor before the conceptual model is accepted as validated and is used to support subsequent simulation development.

Additional Conceptual Model Validation Considerations

1. Costs and limits on conceptual model validation

Resources required to perform conceptual model validation depend upon the size and complexity of the simulation being reviewed, the quality and correctness of the conceptual model documentation, and the amount of assurance in simulation validity required.

2. Simulation space and mission space

The conceptual model for a simulation has to address both the simulation space (the simulation operational and functional capability) and the mission space (the representational capability of the simulation). Comments thus far about conceptual model validation have focused on representational issues of mission space. However, conceptual model validation reviews also should address simulation space issues.

Simulation space considerations might have to do with standards compliance required by simulation requirements, data collection capabilities for analysis of simulation results, simulation capabilities to allow user/operator observation and manipulation of the simulation while it is running, etc. Simulation space considerations that must be addressed in conceptual model validation reviews are those covered by simulation requirements and criteria specified for the conceptual model validation review.

References

1. Law, A. M., "Simulation Model's Level of Detail Determines Effectiveness," *Industrial Engineering*, vol. 23, no. 10, pp. 16-18, 1991.
2. Robinson, St., Brooks, R., Kotiadis, K., & van der Zee, D-J. (Eds.), *Conceptual Modeling for Discrete-Event Simulation*, CRC Press, 2010.
3. Emsyne Software Division of the Muthoot Group, "Product Life Cycle Management," available from the Emsyne website at <http://www.emsyne.com/html/emsyne-product-life-cycle-management.htm>, accessed 24 March 2011.
4. Visible Systems Corp., "Typical Product Life Cycle," available from the Visible Systems website, <http://www.visible.com/Products/LCSIS/lifecycle.htm>, accessed 24 March 2011.
5. Ezeenet Computers, "Web Designing," available from the Ezeenet website at http://ezeenet.co.in/web_designing.html, accessed 24 March 2011.
6. FEV, "Solving Problems: Analysis and prediction," available from the FEV website at <http://www.fev.com/content/public/default.aspx?id=445>, accessed 24 March 2011.

7. Art to Part Solutions, "How We Do it," available from the Art2Part website at <http://www.art2part.net/>, accessed 24 March 2011.
8. Loker, S., & Clark, J. T., "Product Development Stages" in *The Cutting Edge Apparel Business Guide: A Web-Based Course*, Cornell University, 2006, available at <http://courses.cit.cornell.edu/cuttingedge/productDev/14prodDev.htm>, accessed 24 March 2011.
9. Defense Modeling and Simulation Office (DMSO), *CMMS Technical Framework*, USD/A&T-DMSO-CMMS-0002 Revision 0.2.1, 1997.
10. Mojtahed, V., Lozano, M., Svan, P., et al., DCMF: *Defence Conceptual Modeling Framework*, Swedish Defence Research Agency (FOI) Report FOI-R-1754-SE, November 2005.
11. Pace, D. K., "Thoughts About the Simulation Conceptual Model," *2003 Spring Simulation Interoperability Workshop*, paper 03S-SIW-009. 2003.
12. Institute of Electrical and Electronics Engineers (IEEE) Standard 1516.4TM (IEEE Std 1516.4TM=2007), *IEEE Recommended Practice for Verification, Validation, and Accreditation of a Federation – An Overlay High Level Architecture (HLA) Federation Development and Execution Process*, 20 December 2007.
13. Hamill, M., & Goseva-Popstojanova, K., "Common Trends in Software Fault and Failure Data," *IEEE Transactions on Software Engineering*, Volume 35 (4), pp. 484–496, 2009
14. Jacobson, I., Christerson, M., Jonsson, P., & Overgaard, G., *Object-Oriented Software Engineering: A Use Case Driven Approach*, ACM Press/Addison-Wesley, 1992.
15. Pace, D. K., "Impact of Simulation Description on Conceptual Model Validation," *Proceedings of the Fall 1998 Simulation Interoperability Workshop*, September 14-18, 1998, Orlando, FL.
16. Balci, O., & Ormsby, W. F., "Conceptual Modelling for Designing Large-Scale Simulations," *Journal of Simulation*, Volume 1, pp. 175–186, 2007.
17. Sheehan, J., Prosser, T., Conley, H., Stone, G., Yentz, K., & Morrow, J., "Conceptual Models of the Mission Space (CMMS): Basic Concepts, Advanced Techniques, and Pragmatic Examples," *98 Spring Simulation Interoperability Workshop Papers*, Volume 2, pp. 744–751, March 1998.
18. Johnson, T. H., "Mission Space Model Development, Reuse and the Conceptual Models of the Mission Space Toolset," *98 Spring Simulation Interoperability Workshop Papers*, Volume 2, pp. 893–900, March 1998.
19. Roache, P. J., *Verification and Validation in Computational Science and Engineering*, Hermosa Publishers, Albuquerque, New Mexico, 1998.

20. Thalheim, B., Schewe, K-D., & Ma, H., "Conceptual Application Domain Modelling," *Sixth Asia-Pacific Conference on Conceptual Modelling (APCCM 2009)*, New Zealand, available in *Research and Practice in Information Technology*, Vol. 96, and at <http://crpit.com/confpapers/CRPITV96Thalheim.pdf> (accessed September 2010).
21. Wainer, G. A., *Discrete-Event Modeling and Simulation: A Practitioner's Approach*, CRC Press, 2009.
22. Zeigler, B. P., & Hammonds, P. E., *Modeling & Simulation-Based Data Engineering: Introducing Pragmatics into Ontologies for Net-Centric Information Exchange*, Elsevier Academic Press, 2007.
23. Zeigler, B. P., Praehofer, H., & Kim, T. G., *Theory of Modeling and Simulation*, second edition, New York, Academic Press, 2000.
24. *Department of Defense Standard Practice: Documentation of Verification, Validation, and Accreditation (VV&A) for Models and Simulations*, MIL-STD-3022, dated 28 January 2008.
25. Institute of Electrical and Electronics Engineers (IEEE) Standard 1516.3™ (IEEE Std 1516.3™--2003), *IEEE Recommended Practice for High Level Architecture (HLA) Federation Development and Execution Process (FEDEP)*, 23 April 2003.
26. Institute of Electrical and Electronics Engineers (IEEE) P1730-2010™ *Recommended Practice for Distributed Simulation Engineering and Execution Process (DSEEP)*, 24 January 2011.
27. *A Glossary of Modeling and Simulation Terms for Distributed Interactive Simulation (DIS)*, August 1995.
28. Institute of Electrical and Electronics Engineers (IEEE) P1730-2010™, *Recommended Practice for Distributed Simulation Engineering and Execution Process (DSEEP); Appendix B: Distributed Interactive Simulation (DIS) Process Overlay to the DSEEP*, 24 January 2011.
29. Lemmers, A. J. J., Keuning, M. F. R., & Jokipii, M., *SEST: SE Specification Tool-set*, The Netherlands National Aerospace Laboratory NLR Report NLR-TP-2003-570, November 2003 (report based upon "SEST: SE Specification Tool-set," *2003 Fall Simulation Interoperability Workshop*, paper 03F-SIW-060, 2003).
30. Tanriover, O. Ozgur, and Semih Bilgen, "Chapter 15: UML-Based Conceptual Models and V&V," *Conceptual Modeling for Discrete-Event Simulation*, Stewart Robinson, Roger Brooks, Kathy Kotiadis, and Durk-Jouke van der Zee, eds., CRC Press, pp. 383–419, 2010.
31. deSylva, Mike, Robert Lutz, and Scott Osborne, "The Application of the DoDAF within the Federation Development Process," *2004 Fall Simulation Interoperability Workshop*, paper 04F-SIW-015, 2004.

32. Brade, Dirk, "Conceptual Modeling Meets Formal Specification," *2003 Spring Simulation Interoperability Workshop*, paper 03S-SIW-138, 2003.
33. Hudgins, Gene, Keith Poch, and Juana Secondine, "TENA and JMETC, Enabling Technology in Distributed LVC Environments," *Proceedings of AIAA USAF T&E Days Conference*, AIAA 2010-1745, February 2010.

Acronyms

AIAA	American Institute of Aeronautics and Astronautics
APCCM	Asia-Pacific Conference on Conceptual Modelling
CMMS	Conceptual Models of the Mission Space
DCMF	Defence Conceptual Modeling Framework
DIS	Distributed Interactive Simulation
DoD	Department of Defense
DoDAF	Department of Defense Architecture Framework
DSEEP	Distributed Simulation Engineering and Execution Process
FDMS	Functional Description of the Mission Space
FEDEP	Federation Development and Execution Process
FOM	Federation Object Model
HLA	High Level Architecture
IEEE	Institute of Electrical and Electronics Engineers
IV&V	Independent Verification and Validation
JMETC	Joint Mission Environment Test Capability
LVC	Live-Virtual-Constructive
M&S	Modeling and Simulation
MIL-STD	Military Standard
RPG	Recommended Practices Guide
SIW	Simulation Interoperability Workshop
SME	Subject Matter Expert
SOM	Simulation Object Model
SysML	Systems Modeling Language
T&E	Test and Evaluation
TENA	Test and Training Enabling Architecture
UML	Unified Modeling Language
V&V	Verification and Validation
VV&A	Verification, Validation, and Accreditation

The appearance of hyperlinks does not constitute endorsement by the DoD, M&S CO, the administrators of this website, or the information, products, or services contained therein. The DoD does not exercise any editorial control over the information found at these locations. Such links are provided consistent with the stated purpose of this website.