Modeling and Simulation Management Plan

Document change record

Version Number	Change	Date
1.0	Modeling and Simulation Management Plan	

Contents

1. Introduction

A model is a physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process. A simulation is a method for implementing a model over time using operating conditions and inputs. Models and Simulations (M&S) are Systems Engineering tools used by multiple functional area disciplines during all life-cycle phases. Modeling is essential to aid in understanding complex systems and system interdependencies and to communicate among team members and customers. Simulation provides a means to explore concepts, system characteristics, test alternatives, open up the trade space, facilitate informed decisions and assess overall system performance. The Project uses models that acknowledge a level of risk appropriate to the application (see DoD Instruction 5000.61, DoD Modeling and Simulation (M&S) Verification, Validation, and Accreditation (VV&A)). Note that this information can be gathered without the cost of building real hardware.

M&S is a tool used in Systems Engineering to gather information to help make decisions. It's normally used in product development to help define/refine requirements and for testing or analyzing a system or process. M&S can utilize emulators, prototypes, simulators, and stimulators to develop data. It is intended to provide an operationally valid environment to explore concepts and refine capability requirements in preparation for field experimentation. Typical programs use M&S to:

1. Develop the system concept
2. Design the system, including its sustainment
3. Assess the merits of alternatives throughout the development cycle
4. Integrate the system
5. Test the system to verify it meets requirements
6. Support system introduction, sustainment and evolution
7. Model alternatives

M&S decreases the risk to the customer by: enabling repetitive and varying tests unconstrained by time or space; saving time and resources by assessing effectiveness during all phases of development; and using synthetic environments replicating realistic testing scenarios.

2. Definitions

A model is a representation of the construction and working of the system of interest. A model is similar to but simpler than the system it represents. A simulation is a method for implementing a model.

1. Four (4) common types of models used:
    a) **Physical:** A physical model is a model whose physical characteristics resemble the physical characteristics of the system being modeled. A simple example of a physical model is a plastic airplane you played with in grade school.
    b) **Mathematical:** A mathematical model is a symbolic model whose properties are expressed in mathematical symbols and relationships. Mathematical models are commonly used to quantify results, solve problems and predict behavior. A simple example of a mathematical model is the equation that represents a straight line: $y=mx+b$.
    c) **Process:** Process models are designed to replicate steps in a process or system. All process models allow users to define their processes, workflows or system dynamics.

Other common processes that are modeled are information flow through a system and the manufacturing of parts using an assembly line.

d) **Combination:** The approach of combining models learned from multiple batches of data as opposed to the common practice of learning one model from all the available data (i.e., the data combination approach).

2. Verification - The process of determining that a model or simulation implementation and its associated data accurately represent the developer's conceptual description and specifications. *Did we build the model right?*

3. Validation - The process of determining the degree to which a model or simulation and its associated data are an accurate representation of the real world from the perspective of the intended uses of the model. *Did we build the right model?*

4. Accreditation - The official certification that a model or simulation and its associated data are acceptable for use for a specific purpose. *Is this the right model to use for this purpose?*

A simulator is a device, computer program, or system that performs simulation. A simulation is a method for implementing a model over time. There are three (3) types of commonly used simulations:

1. **Live:** Simulation involving real people operating real systems, it Involves individuals or groups, may use actual equipment and should provide a similar area of operations and be close to replicating the actual activity
2. **Virtual:** Simulation involving real people operating simulated systems. Virtual simulations inject Human-In-The-Loop in a central role by exercising motor control skills (e.g., flying an airplane), decision skills (e.g., committing fire control resources to action) or communication skills (e.g., members of a development team)
3. **Constructive:** Simulation involving simulated people operating simulated systems. Real people can stimulate (make inputs) but are not involved in determining outcomes. Constructive simulations offer the ability to
   a) Analyze concepts
   b) Predict possible outcomes
   c) Stress large organizations
   d) Make measurements
   e) Generate statistics
   f) Perform analysis

3. Systems Engineering Modeling, Simulation, and Analysis Fundamentals

At the Enterprise, the responsibility for planning and coordinating project modeling and simulation efforts belongs to the Project Manager and has been delegated to the Project Systems Engineer. Modeling and simulation efforts are included in the systems engineering effort as part of the Project risk management and cost/schedule planning. Modeling and simulation efforts include identifying metrics that relate the use of modeling and simulation to cost savings and risk reduction. The Enterprise Systems engineers use Project models to define, understand, communicate, assess, interpret, and accept the project scope; to produce technical documentation and other artifacts; and to maintain "ground truth" about the system(s). **Note that the development of models, construction of simulations, and use of these assets to perform project definition and development activities requires collaboration among all project**

stakeholders. Industry Best Practices have indicated that proper use of modeling and simulation throughout the system life cycle is critical for project success.

The Project has identified and is creating a system model that represents all necessary viewpoints on the system design and captures all relevant system interactions. The Project is developing the system model using standard model representations, methods, and underlying data structures. This system model is a product of system, subsystem and design engineering efforts. The Project system model includes, but is not necessarily limited to parametric descriptions, definitions of behaviors, internal and external Interfaces, cost inputs, and traces from operational capabilities to requirements and design constructs. Project modeling and simulation provides critical capabilities to effectively deal with issues including, but not limited to, interoperability, joint operations, and systems of systems across the entire acquisition life cycle.

The system model is a part of, and evolves with, the project development baseline. The system model is to be integrated throughout the project life cycle and across all domains within the current project phase. The Project M&S personnel update the system model throughout the Project life cycle. Capturing these updates in the system model provides continuity among the Project modeling and simulation users and activities. Also during the construction and operation of our models and simulations, the Project M&S personnel ensure the models will be applicable to other project areas such as training and testing. The system model provides source data for the Project to use to construct instantiated models to support system trades; optimizations; design evaluations; system, subsystem, component, and subcomponent integration; cost estimations; etc. It is important that M&S capability be integrated into the Project Test and Evaluation Strategy (TES) and the Project Test and Evaluation Master Plan (TEMP). This will help ensure successful coordination and execution of M&S objectives and capabilities.

3.1 M&S Systems Analysis

A Systems Engineering approach to synthetic environments and Modeling & Simulation (M&S) are themselves systems intended to accomplish particular objectives. It follows that M&S Planning represents the initial steps of a disciplined system engineering approach, the elements of which are:

M&S Requirements Analysis: Defines the program objectives M&S may be able to satisfy. The contexts in which program M&S objectives must be evaluated (i.e., the questions to be answered) should be identified in parallel with the definition of the objectives. For most programs, expected system operating environments (scenarios, use cases) will be based upon proposed system use scenarios, design reference missions, and operational environments. For each pair of an individual M&S objective and expected system operating environment:

1. Domain information should be gathered
2. Decide what entities, attributes, and interactions, have significant impact on the objectives
3. What level of granularity and fidelity they should be represented
4. What user constraints should be taken into account. These include
   a) available staff and funding,
   b) program schedule,
   c) facilities,

d) allowable response time,
e) required run speed (e.g., in real time),
f) security classification,
g) International Traffic and Arms Regulations (ITAR) restrictions,
h) applicable standards,
i) available computing platforms and networks
j) Any other applicable policies.

5. Analysis of Alternative Solutions: Programs should then identify which models or simulations come close to meeting their needs. Careful examination of each candidate tool should include its verification, VV&A records and record the strengths and weakness of each alternative. If no single M&S tool meets requirements, determine whether multiple models and/or simulations, operating serially or in a dynamically-interacting federation, can meet these requirements.

6.Selection of Best M&S Solution: With the list of candidates and their strengths and weaknesses in hand, identify options that seem feasible and investigate them further only to the extent needed to weigh the options and inform a decision whether to borrow, rent, buy, modify, or build the required M&S capability. In some cases, pursuing an alternate, non-M&S means of satisfying the objective may be the best decision. These decisions should weigh the normal factors of performance, cost, schedule, and risk.

7. Procurement or Development of the Selected M&S Capability: Once the best option has been selected, it will be necessary to coordinate to ensure appropriate funding, personnel, facilities, and equipment are available to execute the selected M&S strategy. Resource levels may require the plans be iterated. It is important that the Program Manager (PM) make necessary investments early in the acquisition life cycle to ensure the M&S capability is available when needed.

3.2 Modeling and Simulation Process

Developing a model or simulation is, in itself, a type of “systems engineering” process. The typical waterfall process is shown in Figure 1.

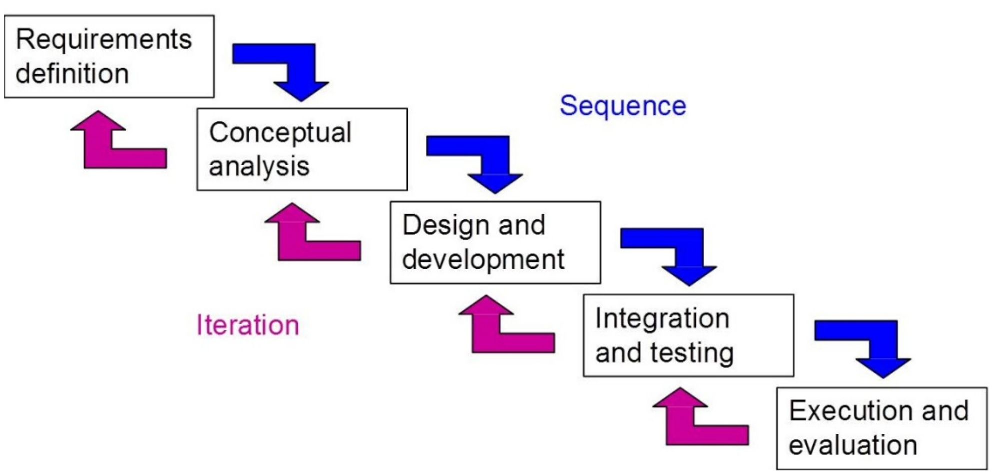

Figure 1: Typical Development Process

The Enterprise Modeling and Simulation Development Process consists of the following steps:

1. Create a Modeling & Simulation Integrated Product Team (IPT) and Identify Roles and Responsibilities
2. Identify problem and objectives - M&S requirements analysis, Analysis of alternative solutions and Selection of best solution
3. Procurement or development of the selected M&S capability
4. Identify High Payback Process Areas from the Project
5. Identify Potential Legacy Systems, Standard Simulations, Architectures and Data Repositories, select the synthetic environments
6. Identify where user and simulators are/will be located
7. Determine capabilities and architectures of existing simulations
8. Identify network bandwidth requirements
9. Identify Integrated Digital Environment (IDE) utilization opportunities
10. Identify interoperability/interface/immersion requirements
11. Required capability cap
12. Design M&S architectures

a) **Collect and Process Real System Data:** Collect data on system specifications, input variables, as well as performance of the existing system.

b) **Formulate and Develop a Model:** Develop schematics and network diagrams of the system. Translate these conceptual models to simulation software acceptable form. Verify that the simulation model executes as intended. Verification techniques include traces, varying input parameters over their acceptable range and checking the output, substituting constants for random variables and manually checking results, and animation.

c) **Validate the Model:** Compare the model's performance under known conditions with the performance of the real system. Perform statistical inference tests and get the model examined by system experts. Assess the confidence that the end user places on the model and address problems if any. For M&S work for DoD contracts, use MIL-STD-3022 (2012), DOCUMENTATION OF VERIFICATION, VALIDATION, AND ACCREDITATION (VV&A) FOR MODELS AND SIMULATIONS to determine what verifications and validations are required.

d) **Document Model for Future Use:** Document objectives, assumptions and input variables in detail. Document the experimental design.

e) **Select Appropriate Experimental Design:** Select a performance measure, a few input variables that are likely to influence it, and the levels of each input variable. Generally, in stationary systems, steady-state behavior of the response variable is of interest. Ascertain whether a terminating or a non-terminating simulation run is appropriate. Select the run length. Select appropriate starting conditions. Select the length of the warm-up period, if required. Decide the number of independent runs – each run uses a different random number stream and the same starting conditions – by considering output data sample size. Sample size must be large enough (at least 3-5 runs for each configuration) to provide the required confidence in the performance measure estimates. Alternately, use common random numbers to compare alternative configurations by using a separate random number stream for each sampling process in a configuration. Identify output data most likely to be correlated.

f) **Establish Experimental Conditions for Runs:** Address the question of obtaining accurate information and the most information from each run. Determine if the system is stationary (performance measure does not change over time) or non-stationary (performance measure changes over time).
g) **Perform Simulation Runs:** Perform runs according to steps above.
h) **Interpret and Present Results:** Compute numerical estimates (e.g., mean, confidence intervals) of the desired performance measure for each configuration of interest. Test hypotheses about system performance. Construct graphical displays (e.g., pie charts, histograms) of the output data. Document results and conclusions.
i) **Recommend Further Courses of Action:** This may include further experiments to increase the precision and reduce the bias of estimators, to perform sensitivity analyses, etc. Note that although this is a logical ordering of steps in a simulation study, many iterations at various sub-stages may be required before the objectives of a simulation study are achieved. Not all the steps may be possible and/or required. On the other hand, additional steps may have to be performed.

13. Utilizing the Existing Enterprise Simulation, Verification, Validation, and Authentication (SVV&A) planning process establish long-term plan, budget, document and implement.
14. Integration, test and evaluation of the M&S capability.
15. Involve the Project Test Team.
16. Application/employment of the modeling and simulation capability.
17. Manage, update, and implement the Project Simulation Support Plan (SSP).

The specific Project M&S Process should identify and show how to provide sufficient training to support the appropriate use of modeling and simulation for the specific Project. The Project M&S Process should identify metrics and track the metrics to support the linkage between the training and increased support to the program. The specific Project M&S Integrated Master Schedule should confirm the model baseline at appropriate technical milestones based on contractual requirements. The specific Project M&S process should construct depictions of system concepts developed in support of required technical reviews using the system model as source data.

4. Configuration Management

Configuration management is just as important for M&S as it is for systems and software engineering. Requirements for model and simulation configuration management are as follows:

1. Identifying the “current version” during development
2. Maintaining a copy of each “release”
3. Tracking defects and their correction
4. Maintaining records of recipients of each version
5. Managing multiple “branches” for multiple users
6. Managing co-developed versions if source is distributed
7. Incorporating externally-made changes in a “baseline” version
8. Regression testing of new versions

All M&S projects will use the Enterprise Configuration Management Process approved for the specific Project to maintain the CM for the M&S.

5. Range of Engineering Disciplines Needed for System Design and Development Simulations

Depending on the specific M&S being considered, personnel knowledgeable/experienced in the following engineering disciplines are required:

1. Modeling and Simulation
2. Structural mechanics/dynamics
3. Fluid dynamics
4. Thermodynamics and heat transfer
5. Propulsion
6. Electrical Engineering
7. Mechanical Engineering
8. Materials engineering
9. Circuit design
10. Electrical power design and distribution
11. Guidance, navigation and control
12. Acoustic propagation
13. Electromagnetic propagation
14. Optical device engineering
15. Communication systems engineering
16. Computer network engineering
17. Software engineering
18. Human-systems integration
19. Manufacturing processes

Specific domain knowledge required, as noted above, will be based on the Project M&S requirements and should be defined in the Project M&S Process documentation.

Appendix A: Definitions

Accuracy – The closeness of a measured or modeled/computed value to its "true" value. The "true" value is the value it would have if we had perfect information. We will talk later about various ways to measure accuracy.
Accreditation - The official certification that a model or simulation and its associated data are acceptable for use for a specific purpose. –Is this the right model to use for this purpose?
Algorithm – A set of rules for solving some problem. On a computer, an algorithm is a set of rules in computer code that solve a problem.
Calibration - The process of adjusting model parameters within physically defensible ranges until the resulting predictions give the best possible fit to the observed data.
Conceptual Model - A hypothesis regarding the important factors that govern the behavior of an object or process of interest. This can be an interpretation or working description of the characteristics and dynamics of a physical system.
Deterministic Model - A model that provides a single solution for the variables being modeled. Because this type of model does not explicitly simulate the effects of data uncertainty or variability, changes in model outputs are solely due to changes in model components.
Empirical Model - An empirical model is one where the structure is determined by the observed statistical relationship among experimental data. These models can be used to develop relationships that are useful for forecasting and describing trends in behavior but they are not necessarily mechanistically relevant that is they don't explain the real causes and mechanisms for the relationships.
Parameters - Terms in the model that are fixed during a model run or simulation but can be changed in different runs as a method for conducting sensitivity analysis or to achieve calibration goals.
Sensitivity - The degree to which the model outputs are affected by changes in a selected input parameters.
Statistical Models - Models obtained by fitting observational data to a mathematical function.
1 Some of these definitions were taken from Glossary of Frequently Used Modeling Terms. http://www.epa.gov/crem/library/glossary.pdf.
Stochastic Model - A model that includes variability in model parameters. This variability is a function of: 1) changing environmental conditions, 2) spatial and temporal aggregation within the model framework, 3) random variability. The solutions obtained by the model or output is therefore a function of model components and random variability.
Validation - The process of determining the degree to which a model or simulation and its associated data are an accurate representation of the real world from the perspective of the intended uses of the model. Did we build the right model? Answers the questions "Is the science valid and does the model use current methods and techniques? Is the numerical model adequate to convey the science principles at the level of the question being asked? Is the model arriving at an acceptably accurate representation of the phenomenon being modeled?"
Variable - A measured or estimated quantity which describes an object or can be observed in a system and which is subject to change.
Verification - The process of determining that a model or simulation implementation and its associated data accurately represent the developer's conceptual description and specifications. Did we build the model right? Does the code for the model run correctly and provide a

mathematically correct answer? Do the algorithms being used accurately represent the mathematical function on the computer?

Appendix B: References

1. MIL-STD-3022, April 2012, DOCUMENTATION OF VERIFICATION, VALIDATION, AND ACCREDITATION (VV&A) FOR MODELS AND SIMULATIONS

2. An Introduction to the Use of Modeling and Simulation Throughout the Systems Engineering Process, 2012 James E. Coolahan

3. DoD Modeling and Simulation Body of Knowledge (BOK), 2008

4. Survey of Model-Based Systems Engineering (MBSE) Methodologies, Jeff A. Estefan, NASA Jet Propulsion Laboratory, May 2008

5. Systems Engineering Modeling, Simulation, and Analysis Fundamentals, DEPARTMENT OF DEFENSE ACQUISITION MODELING AND SIMULATION WORKING GROUP, March 2014