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HOW TO SUCCESSFULLY CONDUCT LARGE-SCALE MODELING AND SIMULATION PROJECTS

Osman Balci

Virginia Tech
Department of Computer Science
3160B Torgersen Hall, MC 0106
Blacksburg, VA 24061, USA

ABSTRACT

Conducting large-scale complex modeling and simulation (M&S) projects continues to pose significant challenges for M&S engineers, project managers, and sponsoring organizations. This advanced tutorial presents an M&S life cycle to alleviate the challenges. The M&S life cycle describes a framework for organization of the processes, work products, quality assurance activities, and project management activities required to develop, use, maintain, and reuse an M&S application from birth to retirement. It provides guidance to an M&S developer (engineer), manager, organization, and community of interest. The M&S life cycle specifies the work products to be created by executing the corresponding processes together with the integrated verification, validation and quality assurance activities. The M&S life cycle is critically needed to modularize and structure a large-scale M&S application development, and to provide valuable guidance for conducting an M&S project successfully.

1 INTRODUCTION

The U.S. Government continues to be the largest sponsor and consumer of modeling and simulation (M&S) applications in the world. The U.S. Department of Defense (DoD) annually spends more than a billion dollars for the development, use, and maintenance of M&S applications. Recently, the U.S. Missile Defense Agency (MDA) awarded a $595 million contract for the development of an M&S application to evaluate elements of the Ballistic Missile Defense System before their deployment (Quinn 2011). Such multi-million-dollar M&S application development projects carry a high risk of failure unless they are conducted properly.

An M&S project is considered successful if it produces sufficiently credible M&S results that are accepted and used by the decision makers or sponsor. Many things can go wrong in an M&S project. An M&S application can produce unacceptable results because of many reasons including the following: (a) M&S application is developed to solve the wrong problem because of ill-defined M&S Intended Uses (Balci and Ormsby 2000), (b) A simulation model is developed with sufficient validity in representing the system as it is defined, but the system is defined improperly, (c) Inaccurate experimentation with a sufficiently valid simulation model, (d) An M&S application is reused for the Intended Uses for which the M&S application is not created for, (e) M&S application does not possess sufficient validity, and (f) The results of a sufficiently credible M&S application are incorrectly presented to the decision makers resulting in the rejection or improper use of the results.

A large-scale M&S application development requires many areas of expertise including simulation modeling methodology, software engineering, statistics, systems analysis, project management, and problem domain-specific knowledge. The simulation modeling methodology depends on the area (type) of M&S. Balci, Arthur, and Ormsby (2011) describe 17 M&S areas including discrete, continuous, Monte

Carlo, system dynamics, and agent-based. The use of these M&S types spans dozens of different disciplines for many Intended Uses.

The purpose of this advanced tutorial is to provide guidelines on how to conduct an M&S project in accordance with the M&S life cycle created by the author to increase the probability of success. The M&S life cycle is presented in Section 2. Concluding remarks are given in Section 3.

2 A LIFE CYCLE FOR MODELING AND SIMULATION

A life cycle for M&S created by the author is presented in Figure 1. The M&S life cycle represents a framework for organization of the processes, work products, quality assurance activities, and project management activities required to develop, use, maintain, and reuse an M&S application from birth to retirement. The M&S life cycle is created to modularize and structure an M&S application development and to provide guidance to an M&S developer (engineer), manager, organization, and community of interest.

The M&S life cycle represents a dozen processes organized in a logical order, as depicted in Figure 1, starting with Problem Formulation and culminating with Reuse. Nine more processes are listed in Figure 1 to represent other aspects of the M&S life cycle.

A *process*, represented by a double-line arrow, is executed to create a work *product*. For example, we execute the process of Conceptual Modeling to create a Conceptual Model or the process of Design to create a Design Specification. A work *product* is created in different forms, i.e., document, model, executable, results, or repository, as shown with different symbology in Figure 1.

The M&S life cycle should not be interpreted as strictly sequential or linear. The sequential representation of the double-line arrows is intended to show the direction of workflow throughout the life cycle. The life cycle is iterative in nature and reverse transitions are expected. For example, an error identified during verification and validation (V&V) of an executable submodel may require changes in the requirements specification and redoing the earlier work. We typically bounce back and forth between the processes until we achieve sufficient confidence in the quality of the work products.

In the following sections, we provide guidelines throughout the M&S life cycle for successfully conducting a large-scale M&S project. For detailed information about the M&S life cycle, the reader is referred to Balci (2011).

2.1 Problem Formulation

The Universe of Discourse, the starting point for the life cycle, refers to a specific problem domain for a Community of Interest (COI). For example, for the Ballistic Missile Defense (BMD) COI, the Universe of Discourse can be defined as a class containing all the entities referred to in a BMD discourse, or as an inclusive class of entities that is tacitly implied or explicitly delineated as the subject of a statement, discourse, or theory related to BMD.

For example, in one BMD COI's Universe of Discourse (problem domain), BMD engineers try to model and simulate the trajectory of an exoatmospheric ballistic missile for the Intended Use of estimating the position of the missile after Δt time units given its current position. This estimation problem, called Signature M&S, is critically important for deciding when to fire the ground-based or sea-based kill vehicle to intercept the incoming missile. Such M&S-based estimation is very complex since the missile trajectory is influenced by many factors including missile speed, gravity, temperature, composition of the missile hard body and its chemical interactions with atmosphere, and position of the sun and moon.

Problem Formulation (a.k.a. Problem Structuring or Problem Definition) is the process by which the Universe of Discourse is analyzed to create a Formulated Problem, which is sufficiently well defined to enable specific action. This process takes the Universe of Discourse description as input and produces the work product Formulated Problem as output. Problem Formulation is the beginning of every problem solving methodology / project.

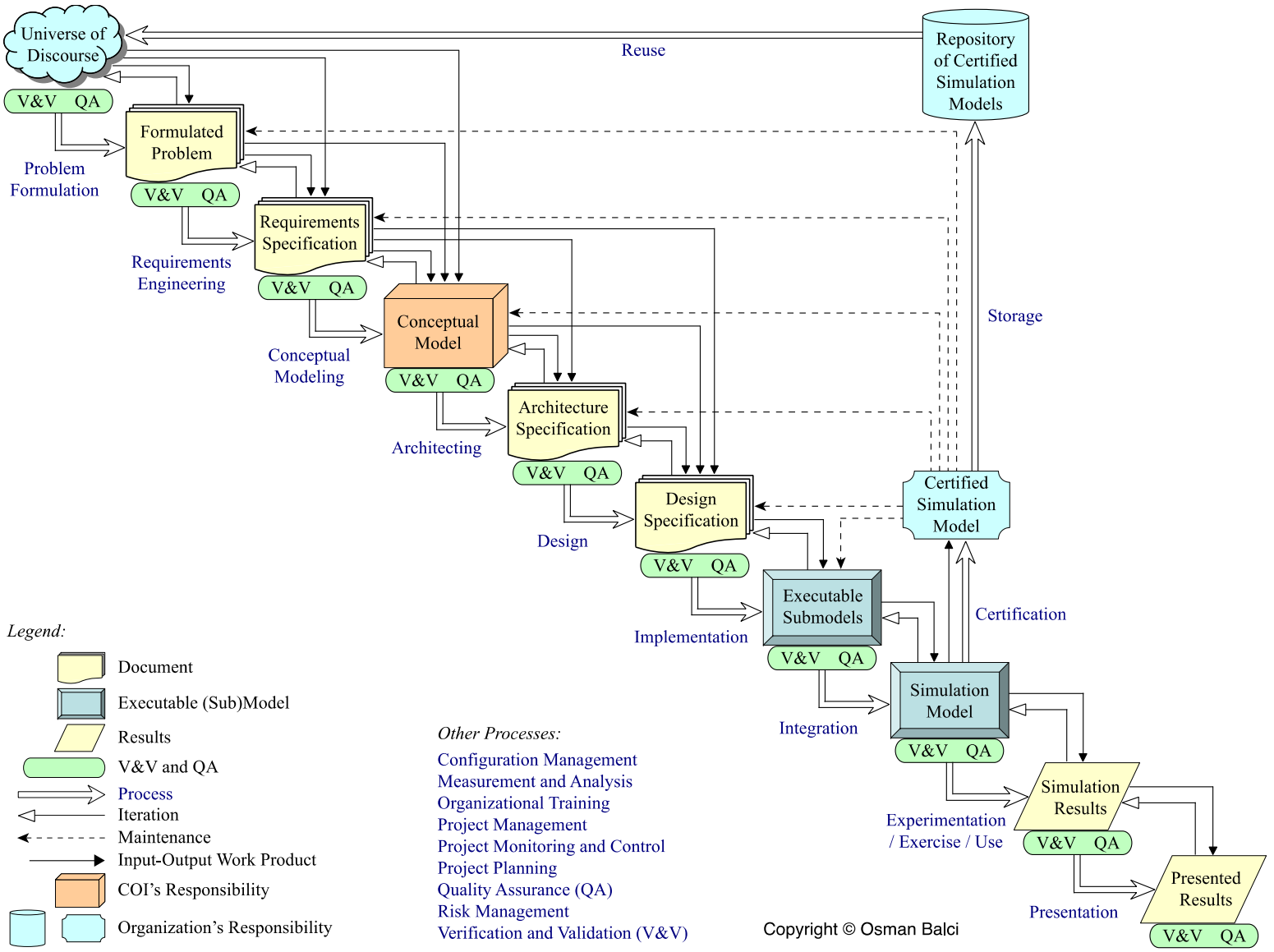

Figure 1: A Life Cycle for Modeling and Simulation

Unfortunately, the process of Problem Formulation is not given sufficient attention during the M&S life cycle without realizing that the accuracy of Problem Formulation greatly affects the acceptability and credibility of M&S application results. *Type III Error* is defined as the error of solving the wrong problem and is committed in this process (Balci 2010).

2.2 Requirements Engineering

Requirements Engineering is the process of elicitation of requirements based on the formulated problem and the universe of discourse, and specification of the requirements in an authoritative manner. This process takes the Formulated Problem and the problem domain (Universe of Discourse) as input and produces an M&S Requirements Specification Document (RSD) as the output work product. The M&S RSD becomes part of a legal contract between the M&S developer and the M&S sponsor.

Requirements Engineering *Quality Assurance* (QA) should be conducted by integrating the assessments of quality of the M&S RSD work *product*, requirements engineering *process* quality, quality of the *people* employed in requirements engineering, and *project* characteristics related to this life cycle stage.

The M&S RSD should clearly dictate the *M&S Acceptability Criteria* with respect to which the delivered M&S application will be judged so as to prevent any "finger pointing" during Acceptance Testing.

An M&S application's Intended Use refers to the explicitly and clearly defined purpose for which the application is intended for use (Balci and Ormsby 2000). Intended Uses (Objectives) should be properly defined in this process since they become the point of reference for the rest of the M&S life cycle. V&V and QA are carried out throughout the M&S life cycle with respect to the defined Intended Uses.

An M&S requirement should be specified using "shall", e.g., "a simulation model user *shall* be able to specify the number of simulation runs to perform."

An M&S requirement should be engineered as a product with a set of required quality characteristics such as accuracy, clarity, completeness, consistency, feasibility, modifiability, testability, and traceability.

2.3 Conceptual Modeling

A simulation *Conceptual Model* (CM) is a repository of high-level conceptual constructs and knowledge specified in a variety of communicative forms (e.g., animation, audio, chart, diagram, drawing, equation, graph, image, text, and video) intended to assist in the design of any type of large-scale complex M&S application (Balci and Ormsby 2007; Balci, Arthur, and Ormsby 2011).

Conceptual Modeling is the process of developing the highest layer of abstraction / representation, which is closer to the level of thinking of a simulation model designer, for specifying high-level conceptual constructs and knowledge in a variety of communicative forms intended to assist in the design of any type of large-scale complex M&S application. This process takes the M&S RSD, Formulated Problem, and problem domain (Universe of Discourse) as input and produces a Conceptual Model specification as the output work product.

A CM should be created and maintained for a COI under the leadership and funding of a leading organization in that COI and should be provided for use by the simulation model designers in that COI. Many COIs exist such as air traffic control, automobile manufacturing, ballistic missile defense, business process reengineering, emergency response management, military training, network-centric operations and warfare, supply chain management, telecommunications, and transportation.

For example, Federal Emergency Management Agency (FEMA) can lead the development of a CM for the Emergency Response Management COI to assist in the design of M&S applications in that COI; National Institute of Standards and Technology (NIST) can lead the development of a CM for the Manufacturing COI to assist in the design of M&S applications in that COI; and Missile Defense Agency (MDA) can lead the development of a CM for the Ballistic Missile Defense COI to assist in the design of M&S applications in that COI.

A CM becomes an asset for a COI and provides significant economical benefits through its reuse in designing many simulation models within the problem domain of that COI.

2.4 Architecting

Architecting is the process of creating and specifying an architecture for a network-centric M&S application based on the Conceptual Model and the M&S RSD. The process of Architecting takes the Conceptual Model and M&S RSD as input and produces a network-centric M&S application's Architecture Specification as the output work product. The process of architecting can be conducted under the guidelines provided by Chigani and Balci (2011).

The output, *Architecture Specification*, refers to the fundamental organization of M&S application components that interoperate over a network (e.g., Internet, virtual private network, wireless network), relationships among the M&S application components, and the principles and guidelines governing the design and evolution of those components. An M&S application architecture is specified by typically using U.S. Department of Defense (DoD) Architecture Framework (DoDAF), which provides 52 diagrams for representing an architecture (DoDAF 2009).

High Level Architecture (HLA) is the DoD / IEEE / NATO Standard network-centric (i.e., distributed) simulation architecture (IEEE 2000). Other architectures are also available for M&S applications such as Client-Server Architecture (CSA), Distributed Objects Architecture (DOA), and Service-Oriented Architecture (SOA). For example, Myers and Balci (2009) present a web-based visual simulation architecture based on CSA. Balci and Page (2009) introduce potential technologies for engineering network-centric M&S applications.

Architecting QA should be conducted by integrating the assessments of quality of the Architecture Specification work product, architecting process quality, quality of the people employed in architecting, and project characteristics related to the life cycle stage for architecting.

2.5 Design

The process of *Design* deals with the instantiation (creation) of a design of the M&S application from the Architecture Specification. The Design process takes the M&S RSD, Conceptual Model, and Architecture Specification as input and produces a Design Specification of the M&S application as the output work product.

M&S application Design is created in accordance with the M&S area (type). For example, a continuous simulation model is designed using differential equations; a Monte Carlo simulation model is designed using statistical random sampling; and a system dynamics simulation model is designed using rate equations.

M&S application Design QA should be conducted by integrating the assessments of quality of the M&S application Design Specification work product, design process quality, quality of the people employed in design, and project characteristics related to the life cycle stage for design.

2.6 Implementation

Implementation is the process of programming a simulation model design specification by using a simulation software product (e.g., Arena, AutoMod, ProModel) or a high-level programming language (e.g., C, C++, C#, Objective C, Java).

A simulation model is decomposed into submodels (modules or components) to overcome the complexity. This process takes the simulation model Design Specification as input and produces the Executable Submodels as the output work product. For large complex simulations, different submodels (components) can be contracted out to different companies for development or can be developed by different teams or groups within the same company.

2.7 Integration

Integration is the process of combining the individually developed submodels. This process takes the Executable Submodels as input and produces the integrated Simulation Model as a finished product.

Integration QA should be conducted by integrating the assessments of quality of the simulation model work product, integration process quality, quality of the people employed in integration, and project characteristics related to the life cycle stage for integration.

2.8 Experimentation, Exercise or Use

Experimentation / Exercise / Use is the process in which the finished Simulation Model is experimented with (for problem solving), exercised (for training purposes), or otherwise used. This process produces the Simulation Results based on the experimentation, exercise or use. The simulation results make up the solution to the problem (for problem solving), show effectiveness of training (for training purposes), or indicate some benefit in using the simulation model (e.g., for research).

2.9 Presentation

Presentation is the process of (a) interpretation of the simulation results, (b) documentation of the simulation results, and (c) communication of the simulation results to the decision makers.

A *descriptive model* is a model which describes the behavior of a system without any value judgment on the "goodness" or "badness" of such behavior. All simulation models are descriptive models and their results must be interpreted.

Due to the complexity of some simulation results, failing to properly interpret, document, and communicate the simulation results may lead to wrong decisions in spite of the fact that the simulation results are sufficiently credible.

2.10 Certification

Certification is the process of independently awarding a "Certificate", a "Seal of Approval" or a "Mark of Conformity" formally attesting that a simulation model fulfills specific quality criteria under a set of prescribed Intended Uses.

Certification is defined as a "procedure by which a third party gives written assurance that a product, process or service conforms to specified characteristics" (ISO 2011).

Certification is the responsibility of the organization that sponsored the M&S application development. The independent award is regarded by the M&S application sponsor as providing some form of guarantee of quality and credibility. Based on the guarantee, the sponsor decides to use the simulation results in making key decisions. The consequences of wrong certification may be catastrophic.

2.11 Storage

Creation of an organization-wide Repository of Certified Simulation Models is the responsibility of any organization that develops and uses M&S applications on a regular basis. A Certified Simulation Model becomes an asset for an organization (e.g., DoD, FEMA, MDA, National Aeronautics and Space Administration, NIST) and must be preserved and reused.

The process of *Storage* places the Certified Simulation Model with its full documentation and data into an organization-wide repository for reuse. Storage of models, submodels, documentation, and data should be done using metadata to facilitate the search and retrieval operations.

2.12 Reuse

The process of *Reuse* deals with the reuse of models or submodels from the Repository of Certified Simulation Models.

3 CONCLUDING REMARKS

Modularization or decomposition stands out to be the best approach to employ when faced with significant complexity of a large-scale M&S application. The use of a life cycle is critically important to modu-

larize and structure the development of a large-scale M&S application and provide valuable guidance for project management. The life cycle enables the M&S project managers to decompose the work in terms of processes and work products and to identify areas of expertise in which to employ qualified people. Effective use of the M&S life cycle presented herein significantly increases the probability of success in a large-scale M&S application development project.

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AUTHOR BIOGRAPHY

OSMAN BALCI is a Professor of Computer Science at Virginia Polytechnic Institute and State University (Virginia Tech). He received B.S. and M.S. degrees from Boğaziçi University (Istanbul) in 1975 and 1977, and M.S. and Ph.D. degrees from Syracuse University in 1978 and 1981. Dr. Balci currently serves as an Area Editor of *ACM Transactions on Modeling and Computer Simulation*, Modeling and Simulation (M&S) Category Editor of *ACM Computing Reviews*, and Editor-in-Chief of *ACM SIGSIM M&S Knowledge Repository*. He served as the Editor-in-Chief of two international journals: *Annals of Software Engineering*, 1993-2002 and *World Wide Web*, 1996-2000. He served as Chair of ACM SIGSIM, 2008-2010; and Director at Large of the Society for M&S International, 2002-2006. Most of Dr. Balci's work has been funded by the U.S. Navy since 1983. His current areas of expertise center on software engineering, software/system architecting, and M&S. His e-mail and web addresses are balci@vt.edu and http://manta.cs.vt.edu/balci.