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A SPECIFICATION FOR EFFECTIVE SIMULATION PROJECT MANAGEMENT

Allen G Greenwood

FlexSim Software Products, Inc.
Canyon Park Technology Center, Building A, Suite 2300
1577 North Technology Way
Orem, UT 84097, USA

ABSTRACT

This paper proposes a specification for effectively defining and managing simulation projects. The specification provides a structured and ordered series of tasks that need to be completed in order for a simulation endeavor to be successful; i.e., it sets forth a set of requirements to guide a simulation project through the Project Management Institute's five phases: initiation, planning, execution, monitoring and controlling, and closing. The specification is applicable to any type of simulation, in any domain, for any purpose, and for any scale. Similarly, it can be used with any simulation software.

1 INTRODUCTION

As the title implies, simulations are considered projects. In this paper, a simulation is defined as the act of applying modeling and analysis methods, through technology, to support problem solving and decision making. According to the Project Management Institute (PMI), a project is a "temporary endeavor undertaken to create a unique product, service, or result." (Project Management Institute 2017) Obviously, based on these definitions, simulations are clearly projects.

All projects, large and small, exhibit some common characteristics; these characteristics are described below in the context of a simulation. Key terms are italicized for emphasis.

Every project has a set of *stakeholders* – people who affect, or are affected by, a project's activity or outcome. Typically, there are multiple stakeholders in a simulation project. As discussed further below, identifying the stakeholders and their roles in a project must be performed very early in a simulation project. The primary stakeholder in any project is the *customer* since the main goal of any project is to satisfy the needs of a customer. Therefore, customer needs must be clearly articulated and converted into well-defined, agreed-upon project *objectives* early in a simulation project.

Every project is *unique* and *dynamic*; i.e. every project is different and will *change* over its duration. These two characteristics insert risks and uncertainty into a project. The more types of systems and problems that are considered, and the more stakeholders that are involved, the more uncertain the success of the project becomes. As uncertainly increases, more time must be allocated to deal with problems that will arise and this must be accounted for when developing a project plan.

A project is *temporary* in that it has a defined beginning and end in time. Therefore, projects have a *life cycle* and evolve through *phases*. It is commonplace in projects for the end point, often referred to the *due date*, to slip due to problems and uncertainties that arise as the project is being executed.

A project is actually a *process*; i.e., it involves a coordinated flow of related activities across time and place that collectively creates value for a customer by converting inputs (resources) into outputs (results). Each activity in a process consumes a diverse set of scarce *resources*.

Resources are a key driver in what is referred to as the *project triangle* or *triple constraints* of projects – scope, schedule/time, and cost. *Scope* is defined as the work, or sequence of tasks, that need to be completed by resources in order to realize a project's objective(s). *Schedule* is the time required to complete the scope. *Cost* is the financial commitment needed to complete a project's scope. The triple constraints form the project's boundary, the metrics that drive the project, and the basis for management tradeoffs. The results of the three constraints is the *quality* of the work or deliverables.

Project management is about balancing the constraints. Usually at least one of the constraints is fixed; e.g., the level of available funding or budget is fixed or the project's due date may be fixed. It is important to identify which constraint is fixed at the beginning of a project because this is helpful in addressing how to deal with problems that arise. If, for example, a project must be completed by a certain date and a problem arises that would delay the project's completion, the delay can be mitigated by (1) increasing spending (e.g., adding more labor or other resources), (2) reducing the scope or planned outcomes, or (3) a combination of increased spending and reduced scope.

Another way to view the project triangle is to substitute the words "good" for scope, "fast" for schedule, and "cheap" for cost and consider them to be delivery objectives. Oftentimes it is considered realistic to only achieve two of these objectives. For example, it is possible to deliver a project of high quality and do so fast, but not cheaply as well; similarly, a project can be delivered fast and cheap, but it will likely be of low quality (not good). Therefore, it is important to identify very early in a project, the two fundamental delivery objectives for the project since they will likely impact the technical objectives and constraints.

All of the above characteristics of projects make it paramount that simulation project activities must be *planned* and *managed* in order for the endeavor to be effective and successful.

Pereira et al. (2018) indicate that most of the literature on simulation is focused on technical topics concerned with modeling and analysis; and, there is little discussion of simulation and project management. They propose an approach for applying project management principles in simulation studies; however, their approach is quite different than the one posed here. The two approaches are complementary, not conflicting.

This paper is organized as follows. Section two describes the foundations for the proposed specification. Section three defines and describes the specification for effectively managing simulation projects. Section four provides conclusions.

2 FOUNDATION OF THE SPECIFICATION

The proposed specification, which provides structure and guidance for defining and managing simulation projects, is based on three major sources: (1) PMI's five-phased lifecycle, (2) the simulation modeling and analysis process, and (3) a template for documenting simulation projects in Beaverstock et al. (2017). These sources progress from the more general to the more specific in terms of simulation projects.

2.1 Project Management Lifecycle

The overall structure for the specifications is PMI's project lifecycle that is a part of the Project Management Body of Knowledge, referred to as PMBoK, considers project management as a process that has a lifecycle, which is composed of the following five phases. (Project Management Institute 2017)

1. Initiating, setting overall project direction and defining project objectives.
2. Planning, defining a workable scheme to accomplish an objective.
3. Executing, carrying out the plan.
4. Monitoring and Controlling, measuring progress and taking corrective action when necessary.
5. Closing, accepting the product of a project, bringing the project itself to an end, and assessing project performance.

The proposed specification uses this basic structure since many managers are familiar with PMI and PMBoK and thus it adds credibility to the simulation project. For more information on PMI and PMBoK, see, for example (Muldoon 2018; Project Management Institute 2017).

2.2 Simulation Modeling and Analysis Process

As PMI indicates, a project is a process. Similarly, simulations are processes as well. It is common to say that we "simulate something" or "do some simulations." Whether a verb or noun is used, the act or action basically involves modeling a system and then analyzing the system via the model. Two key steps typically come to mind - build a model and perform an analysis. However, these two steps are a part of a larger process. Many have characterized the simulation process in terms of a number of tasks and steps, e.g. Law's ten-step process (Law 2007), Robinson's outline of key stages and processes for a simulation study (Robinson 2004), and one of the earliest renditions of the simulation process is posited in Shannon (1975). These and the many others are quite similar in that they define what needs to be done in a simulation study; the main difference between them is how they explain their approach. Since there is no real standard simulation process, the one that is used in this paper, as shown Figure 1, is from Beaverstock, et al. (2017).

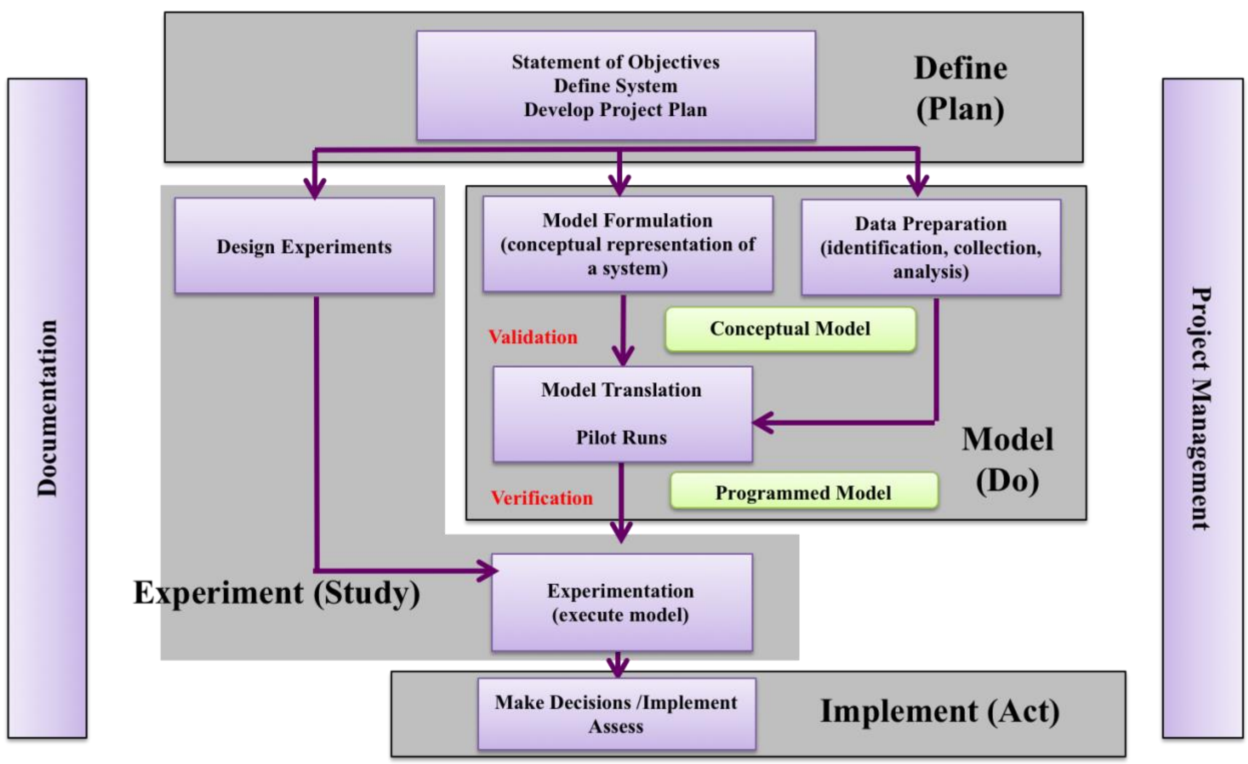

Figure 1: The simulation modeling and analysis process. (based on Beaverstock et al. 2017)

In the process illustrated above, modeling is composed of three related activities - Model Formulation, Model Translation, and Data Preparation - and analysis is composed of two activities - Design Experiments and Experimentation. However, note that there are other sets of activities that precede and follow the model and analyze activities – Define and Implement, respectively. The diagram stresses the importance of the defining and planning activities that must be addressed before modeling starts and the importance of the implementation and assessment activities once analysis is completed. The figure also identifies important activities that span the duration of the endeavor, Documentation and Project Management. Note that the process's four main parts – Define, Model, Experiment, and Implement – correspond to the Deming or PDSA (Plan-Do-Study-Act) cycle that is commonly used in process improvement studies.

2.3 Simulation Documentation

To help operationalize the proposed specification, more detail is needed beyond the two sources described above. The Beaverstock et al. (2017) textbook stresses the application of simulation and provides a chapter on simulation project management. The book also includes a template for documenting a simulation project. While some parts of the template are general, others are specific to modeling and analyzing using the *FlexSim* software. An abbreviated version of the template is shown in Figure 2.

Simulation Project: <name> Version/Date:

Company:
Start Date: End Date: , as of date:
Key words:

Part I - Problem Definition

1. Background (*brief system description, project/problem history*)
2. Objectives (*reason for simulation; expected outcome*)
3. Key performance measures (*basis for choosing among alternatives; define "best" in terms of measures*)
4. Key decision variables (*what is changed among alternatives*)
5. Simulation scope
   a. Defined systems boundaries
   b. Boundary assumptions and conditions
   c. Operating assumptions

Part II - Operational Description

1. System Description (*with supporting diagrams, photos, and historical data*)
2. Key stakeholders

Name	Organization	Position	Contact information	Role

3. Conceptual model /Object Flow Diagram (OFD)
4. Special logic or other considerations to be included
5. References (*for supporting documents*)

Id. No.	Name	Location	Type	Date/Version	Comments

Part III – Simulation Model Development

1. Model file(s)
   a. Software and version
   b. File name(s):
2. Simulation basic units of measure
   1 unit of simulation time =
   1 unit simulation distance =
3. Abbreviations and acronyms (*include color coding*)
4. Object naming convention
5. Modeling simplifications and assumptions
   a. Simplifications
      1. …
      2. …
   b. Assumptions
      1. …
      2. …
   c. Assumptions (to be relaxed)
      1. …
      2. …

…

10. Model views (*screen shots of model*)
11. Model Validation
    a. Validation plan
    b. Validation results
12. Model Verification
    a. Verification plan
    b. Verification results
13. Input data analyses
14. Simulation model version history

Version	Date	Main changes

Part IV - Analysis and Results

1. Analysis questions
2. Definition of performance measures
3. Definition of decision variables
4. Description of analysis process/methodology
5. Tactical information
   a. Initial conditions and basis
   b. Run length and basis
   c. Number of replications and basis
   d. Length of warm-up period and basis
6. Experiments
   a. Description and rationale for experimental design
   b. Input/Output Summary

Scenario	Decision variables					Performance Measu			
	Name 1	Name 2	Name 3	…		PM 1	PM 2	PM 3	
<name>	Val_1								

7. Analysis of simulation experiments
8. Conclusions and recommendations

Figure 2: Simulation project template. (Beaverstock et al. 2017)

This template is used as a foundation, but it is generalized, amended, and re-structured in order to provide an outline and guidelines for defining and managing simulation projects in any project domain and using any simulation software.

3 SIMULATION PROJECT MANAGEMENT SPECIFICATION

The overall structure for the proposed specification for defining and managing simulation project is the five PMI project phases. Each phase contains an ordered series of tasks that need to be completed and identifies some mechanisms and documents for realizing each phase. A good source for more information on the mechanisms and documents that support project management, especially in the context of simulation projects, is Chung (2004).

This paper contains much more definition and discussion of the first two phases and the final phase of the specification since the author believes them critical to project success; and, they are too often given short shrift or are mostly overlooked. All too often simulation projects start almost immediately in the Execution phase, where model building begins, and end when the analyses are complete. There are several common reasons that these phases are inadequately addressed: a lack of understanding of their value, a perception that the aspects addressed in these phases are well known, especially in the first two phases, and the notion that there is not enough time to perform these activities.

All too often when these initial phases are glossed over, there becomes a desperate need later in the project to redo a significant part of the work due to misunderstandings. For example, if the decision maker's decision variables and performance measures are not clearly defined at the beginning of a project, a model may need significant modification late in the project in order to meet the decision maker's need for information. Such modifications typically delay the project or require overtime and cause ill will among the stakeholders. When the final phase is overlooked, there is little opportunity for reflection and feedback, learn what went well and what didn't, and loose the opportunity to improve the simulation process for the next project.

3.1 Initiating Phase

The Initiating phase of a simulation defines a project at a broad level and is composed of three main components – problem definition, operational description, and gateway review. The first two can be done in parallel, but the third results from the first two. Also, there is quite a bit of interplay between the problem definition and the operational description, but they are treated separately since they are often dealt with at different levels. Problem definition is typically addressed at a higher level and is more management or decision-maker focused than the operational description.

3.1.1 Problem Definition

Problem definition includes a problem statement, project objectives, performance measures, decision variables, problem scope, and a brief background narrative of the problem domain.

It is incumbent upon the simulation team to formulate a problem statement that everyone understands and agrees with. Charles Kettering's adage, "a problem well stated is a problem half solved," certainly applies to simulation projects. A clear problem statement is not an easy task. Too often decision makers do not understand simulation and what is involved in a simulation project so it may be unclear to them what problems simulation can handle and which it cannot. Also, all too often the simulation experts do not fully understand the operations and decision-making environment and may be too quick to assume that they do. Oftentimes those creating the simulations too quickly jump to modeling and model what *can* be modeled and not what *should* be modeled. For more information on writing good problem statements, see Lindstrom (2011).

Once the problem is defined, a clear and succinct statement of the project objectives needs to be articulated. A common guideline for defining clear objectives is that they must be SMART (Specific, Measurable, Achievable, Relevant, Time-bound). A good way to start formulating a project's objectives is to, using a Stephen Covey principle, "begin with the end in mind." That is, start by defining the expected outcome(s) of the project and work backwards to the objectives needed to realize the outcome.

There are actually two types of objectives that need to be established early in a project - technical objectives and delivery objectives. The technical objectives relate directly to the problem domain, e.g. improve throughput by determining the best workspace layout or best sequencing rules for processing work. Delivery objectives relate to the project constraints discussed earlier, i.e., which of the three typical project constraints is the most binding – schedule, budget, or scope. Also, delivery objectives are considered in terms of good, fast, and cheap, recognizing that it is likely that only two of these objectives will be realized. Setting delivery objectives early in a project facilitates addressing how to deal with problems that arise later in a project.

Clear project objectives should directly lead to defining and describing key performance measures, primary outputs from a simulation model. When comparing alternative ways to meet an objective, it is imperative to know how the decision maker will deem one option better than another. For example, the option that results in the highest throughput, minimum in-process inventory, and/or highest utilization may be defined as the best. Typically, simulation projects have multiple, oftentimes competing, performance measures. Therefore, it may be necessary to establish how the measures will be traded off. Oftentimes, the decision maker can intuitively make that tradeoff.

Closely related to performance measures are the primary decision variables, one type of input to a simulation model. The decision variables are those factors that the decision maker wants to change in search for better options, such as location of equipment, number of operators, rules for processing work, buffer size, etc.

It is essential to know the decision variables and performance measures at the beginning of a project because it may significantly impact the time to develop a model. Simulation software packages all contain some basic performance measures as output and provide means to specify and modify common decision variables. However, if the project requires non-standard variables and measures, then time must be included in the project plan to incorporate them into the models.

Problem scope, which is different from project scope, includes specifying system boundaries, boundary assumptions, and operational assumptions. The system boundaries are where the simulation analysis begins and ends, typically in a physical sense, such as an individual piece of equipment, work cell, organizational unit, etc. Closely related to the system boundaries are the boundary assumptions and conditions. These explicitly address the representation of inputs to a simulation model from upstream operations and output to downstream operations. For example, upstream processes may be represented as random variables expressed as probability distributions, by a schedule, or are always available to the system being considered. Output to downstream operations may be represented as individual data (e.g. time each item exited the model), summary measure(s) (e.g. mean time between model exits or average throughput rate), or may not be considered at all in the decision-making process.

Operational assumptions are a comprehensive list of conditions in the real system that will not be considered in the model being developed, such as all operators have the same performance (same speed, quality, etc.), the resources are always available and incur no downtime, etc. The initial model will likely have a significant list of assumptions, but many are removed as the model's level of detail evolves. Of course, it is good modeling practice that a model should only be as detailed as it needs to be in order to answer the questions identified in the project objectives.

Finally, the problem definition should include a brief narrative or background that provides context to the remainder of the document. Typically, the background includes a very brief description of the system being considered and a brief history of the problem and any simulation work that precedes the current project.

3.1.2 Operational Description

A simulation project's operational description should include identification of stakeholders, brief description of the system being modeled and analyzed, and the identification of data sources.

Simulation projects typically involve a number stakeholders with diverse roles. Beaverstock et al. (2017) identify the following as the primary stakeholders in a simulation project.

- Decision maker(s)
- Sponsor(s)
- Domain owner(s)
- Domain experts
- Model owner and developer(s)
- Model user(s)
- Information technology

For example, consider a simulation used to support production planning decisions. The vice president of manufacturing may be the ultimate decision maker as to what to produce, when to produce it, and where to produce it. The same individual may be the sponsor, providing funds for model development. The production manager may be the domain owner; the technical staff and production workers may be the domain experts. The model owners may be the industrial engineering department; the model developers may be shared between internal engineers and outside consultants. The model users may be the production planners. Data to run the models may be extracted from the company's databases; therefore, access and other support may be required from information technology.

Beaverstock et al. (2017) also identify and define the following roles that the stakeholders play in a simulation project. Of course, depending on the size and complexity of the project, each role may be fulfilled by multiple people or a person may serve multiple roles.

- Developer – constructs, tests, and documents the simulation model including incorporating the logic, providing physical representations, linking to external data sources, capturing and reporting performance measures, etc. The developer also provides any user interfaces that are required.
- Designer – establishes the architecture of the model and analysis.
- Analyst – designs the experiments, determines the scenario parameters (run length, number of replications, warm-up period, etc.), runs the experiments, prescribes and performs the statistical analyses, and summarizes and documents the results. While much of the analyst's work involves output from a simulation model, their role is to also prescribe model inputs by fitting data to probability distributions, validating input, providing verification information, etc.
- Researcher – early in the project searches to see if similar issues have been addressed previously and summarizes lesson learned from previous work. The researcher may also explore ways to model an aspect of the system, identify an experimental design, determine means to characterize or access data for the model, etc.
- Investigator – probes and "digs" into the system being considered to ensure it is clearly understood and properly represented.
- Educator – helps stakeholders understand enough about simulation to be an effective contributor; typically stakeholders have diverse backgrounds and oftentimes have limited experience in simulation projects.
- Implementer – converts the results of the simulation into actions.
- Manager – leads the planning, organizing, monitoring, controlling, follow-up, and assessment activities, as well as manages expectations.

It is important to realize that for a simulation project to be successful, it is essential to balance technical and people-related issues. In fact, good technical skills and good people skills are each necessary, but not sufficient, conditions for project success. People provide most of a project's domain knowledge and simulation knowledge, as well as validate and verify the models and results.

Another part of the operational description is a brief description of the system including diagrams, photos, system data, etc. as well as references to important documents.

While the identification of data sources may be considered a part of a system description, it is so important, it needs to be called out separately. This activity should include a preliminary review of the availability, structure and format, and quality of the data. Too often data needs are overlooked until much later in a project because it is assumed the needed data are available or domain experts unknowingly ensure data are available but do not understand the form the data need to be in to be used by a simulation model.

3.1.3 Gateway Review

This review with key stakeholders is an essential step to deciding if a proposed project is feasible and should be pursued; i.e., it is expected to meet the customer's needs given the project constraints. The outcome from the review, if the project is deemed feasible, should be a clear understanding by all stakeholders of the objectives and preliminary scope, schedule, and budget. It is also a means to get early buy-in for the project.

As a minimum, minutes of the meeting should document agreement with the problem definition and operational description that are presented and note any changes that have been discussed and approved. All stakeholders should be supplied with the meeting minutes and updated definitions and descriptions. Sometimes the result of the review is referred to as a project charter.

While the project definition is a critical element, it may not always be possible to sufficiently define the scope at the beginning of a simulation project. This may be due to ill-formed or communication-constrained problems, and not just a time issue. It may be due to the concurrence of the decision makers inability to describe the problem and the developer's lack of knowledge of the domain. However, it is important that all stakeholders be aware of the heightened uncertainty and a plan to revisit the definition phase as more clarity is established. This can be handled through one or more action items that remain open until there is sufficient problem definition and/or include multiple gateway reviews.

3.2 Planning Phase

The main components of the planning phase are developing a project plan, describing the system, and formulating a conceptual model. The planning phase culminates in a plan review prior to execution of the project.

3.2.1 Project Plan

A key part of the planning phase is to develop, with significant involvement by the stakeholders, a project plan that identifies and defines at least the main activities/tasks and significant milestones. It also needs to consider the relationship among the activities, e.g. precedence of tasks. The activities and milestones should be displayed on a timescale, e.g., using a Gantt chart.

The activities should also be resource loaded to develop a resource profile that is used to identify the level and timing of resource needs, The profile can then be compared to the resources' availabilities in order to confirm the feasibility of the project plan. In addition to establishing a feasible schedule, the plan is the basis of the project's budget.

The project plan is also used in subsequent phases to track and monitor progress, schedule, and budget and is the basis for project status reviews. The planned status updates, both reviews and reports, should be included as part of the plan. Documentation is often overlooked in simulation projects until near the end of the project; incorporating documentation in the plan makes it a part of the review process and helps assure it is being done on a continued basis. The plan also needs to include a discussion of when and how the simulation model will be validated and verified.

Another helpful part of the plan is developing a responsibility matrix. The matrix explicitly defines the roles and responsibilities of the project stakeholders. In more formal projects, all team members must sign off on the responsibility matrix.

3.2.2 System Description

It is especially important in simulation studies to develop a detailed description of the system being modeled and analyzed. Typically the description is a compilation and assimilation of a number of diagrams and drawings, photos, technical documents, production reports, maintenance records, prior analyses, etc. Simulation projects always require a wide variety of information and oftentimes include product diagrams, process flow charts, facility layouts, product diagrams, technical manuals, value-stream maps, spreadsheets, etc. Information is also oftentimes gathered through interviews/discussions with domain experts and direct observation.

3.2.3 Conceptual Model

The system description and its associated resources is usually converted into a conceptual model. A conceptual model is a non-software specific representation of the system under investigation. Robinson (2017) provides a good introduction to conceptual modeling and Robinson (2011) provides a more in-depth discussion.

Diagramming is an effective way to define and present a conceptual model. One example is the Object-Flow Diagram (OFD) which provides an effective means for representing the salient elements of a system and their relationships. It can be applied to a wide variety of systems, is easy to apply, and is simulation software neutral. See Greenwood et al. (2013) and Beaverstock et al. (2017) for more information on the OFD.

3.2.4 Plan Review

The project plan, system description and conceptual model should be reviewed by stakeholders and each component should be modified based on the feedback from the review. It is important that all stakeholders have the opportunity to participate in the review and that there is agreement on these three components before moving forward with the simulation project.

3.3 Executing Phase

The executing phase is often what one thinks of as undertaking a simulation study – developing, testing, validating, and verifying a simulation model and the analyses that are conducted with the model. Of course, modelers and analysts are the primary stakeholders in this phase; however, domain experts are also very important for defining and clarifying system logic, providing data, verifying models, etc.

3.4 Monitoring and Controlling Phase

Associated with the executing phase is monitoring and controlling project performance. It is important to track and compare actual and planned performance, typically in terms of the status of each task, schedule, and budget. If there is a significant deviation between planned and actual performance, then action must be taken or controls applied to get the project back on track. The project plan must then be updated and stakeholders informed of the changes.

Monitoring and controlling is typically carried out through formal and informal status/progress reports. The reports may be written or made through oral presentations or meetings. While monitoring is often a continuous activity, the reports are typically prepared at specified milestones during the project.

In simulation projects there are typically key reviews at various model stages and especially when the models are validated and verified. Oftentimes there is a project review after initial analyses have been performed with the model. Another key time for a review is when the user interfaces with the model are tested. The project plan should be updated and the stakeholders informed of any changes after each review.

3.5 Closing Phase

The final phase, closing, is often considered synonymous with the implementation of the results, which in the case of many simulation studies is when the final decision that the simulation supported is made. It is also the time when all reports and documentation must be completed, the project team is disbanded, and the budget is closed out.

However, this phase is more than that. It should include a "post mortem" where all of the stakeholders provide lessons learned and feedback on what went well in the project, identify project shortcomings, and identify specific ways things can be improved in the future.

Unfortunately, this phase is too often inadequately performed. However, if the close-out tasks are articulated in the project plan, they are more likely to be completed. Of course, if a project is over budget or late completing, this phase is likely to be minimized. A short shrift in this phase is shortsighted since without a post mortem there is limited opportunity for process improvement.

4 CONCLUSIONS

This paper applies the ways and means of project management to simulation in order to improve the effectiveness of simulation to support problem solving and decision making. The result is a comprehensive specification for what is needed to conduct a successful simulation project. Since all simulation studies are projects, no matter the size or domain, they should be managed as such.

The proposed specification is generic and can be applied to a wide variety of application domains and any simulation software. It is applicable to industry simulation projects, whether it be a quick check by an engineer on some aspect of a design or it is a large-scale, high-risk, enterprise-wide reengineering endeavor. Likewise, the specification is applicable in academe for in-course student projects, simulation-based research (both basic and applied), theses and dissertations, outreach projects with industry, etc. Of course the time and level of detail required will vary depending on the application context, level of risk, complexity of the system, etc. However, at a minimum the specification should be used as a checklist to help ensure all aspects that are critical for success are adequately addressed.

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AUTHOR BIOGRAPHIES

ALLEN G GREENWOOD is professor emeritus in the Department of Industrial and Systems Engineering at Mississippi State University and simulation education specialist at FlexSim Software Products, Inc. He holds a Ph.D. in Management Science, with minors in Statistics and Industrial Engineering, from Virginia Polytechnic Institute and State University. He received his B.S.I.E from North Carolina State University, M.S.I.E. from the University of Tennessee, and is a registered Professional Engineer (retired). His teaching and research interests and expertise include: simulation modeling, analysis, and optimization; project management; and, process design in production and logistics systems. He has extensive industry project experience in a wide variety of domains; his work has been funded by large and small enterprises (e.g., General Electric Aviation, Northrop Grumman, Nissan North America), government agencies (e.g., NASA, Office of Naval Research), and research centers (e.g., Air Force Research Laboratory, Center for Advanced Vehicular Systems). He is co-author of the textbook *Applied Simulation Modeling and Analysis Using FlexSim*. His email address is allen.greenwood@flexsim.com.