# PITFALLS OF SIMULATION MODELING AND HOW TO AVOID THEM BY USING A ROBUST SIMULATION METHODOLOGY

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NOTES

## ABSTRACT

Simulation is a very powerful and flexible tool in the design and analysis of many different types of systems but without a systematic approach, it can be inefficient, expensive, and even misleading. A large number of pitfalls exist on the route to a successful simulation application. In order to avoid these pitfalls, a detailed and rigorous simulation methodology has to be defined and applied through the life of a simulation project. In this paper, we first summarize the pitfalls of a simulation project. Then, we present a detailed simulation methodology that comprises eight major phases. Each phase consists of several steps. It is found that depending on the objectives of the study and the detail level of the problem considered, each of the steps of the methodology may be given different emphasis. We discuss how the methodology avoids the pitfalls of simulation modeling. Two case studies are discussed to highlight some of the steps of this methodology. Adherence to this methodology will ensure the proper usage of this powerful technique and will enable the users to gather better payoffs from the investment on simulation.

## INTRODUCTION

Computer simulation is a technique that allows building of and experimenting with a model of a real system on a computer. The success of a simulation project depends as much on the proper management of the project as on the systems analysis and design techiques applied in the project. A number of articles have been published in the past on the pitfalls of simulation and how to avoid them (Balci 1989, Law and McComas 1990, Musselman 1992, Sadowski 1989, Ulgen et. al. 1994). It has been observed that defining a detailed simulation methodology and rigorously following its steps through the life cycle of a simulation project can avoid most of these pitfalls and ensure a high customer satisfaction for the project.

The purpose of this paper is to introduce a detailed simulation methodology that can be used for applying simulation properly. The methodology consists of eight phases. There are four to thirteen steps identified in each phase. This methodology has been developed and tested by Production Modeling Corporation over the last fifteen years in discrete-event simulation applications. It also has been successfully adopted and used in robotic simulation over the past three years.

In the paper, we first summarize the pitfalls of simulation. Then we describe a detailed methodology for successful simulation applications. The following section discusses how this methodology avoids the pitfalls of simulation modeling. Two case studies are discussed in the following section highlighting the advantages of using this methodology. The final section of the paper gives conclusions on the use of this methodology.

## THE PITFALLS OF A SIMULATION STUDY

A number of articles have been published in the past on the pitfalls of simulation and how to avoid them (Balci 1989, Law and McComas 1990, Musselman 1992, Sadowski 1989, Ulgen et al. 1994). Table 1 below summarizes these pitfalls into three major categories, namely process, model, and people related pitfalls (Musselman 1992). It can be observed that a large number of these pitfalls depend on the proper management of the project. By incorporating the proper simulation project management planning, scheduling, reporting, and control techniques as part of the simulation methodology, one may increase the success of simulation projects significantly. In the following section, we suggest a detailed methodology for execution of simulation projects that incorporates both management and technical issues.

## THE METHODOLOGY

The methodology suggested in this paper has eight phases as given below:

Phase 1. Define the Problem
Phase 2. Design the Study
Phase 3. Design the Conceptual Model
Phase 4. Formulate Inputs, Assumptions, and Process Definition
Phase 5. Build, Verify, and Validate the Simulation Model
Phase 6. Experiment with the Model and Look for Opportunities for Design of Experiments

Phase 7. Document and Present Results
Phase 8. Define the Model Life Cycle

Each phase is described in terms of detailed steps in Table 2. Although these phases are generally applied in sequence, one may need to return to the previous phases due to changes in the scope and objectives of the study. In particular, phases 3 through 6 of the process may be repeated for each major alternative studied as part of the project.

It should be noted that the items listed for Phase 5 and Phase 7 are interpreted as guidelines rather than steps. In previous papers (Ulgen, Black, Johnsonbaugh, and Klungle 1994a and Ulgen, Black, Johnsonbaugh, and Klungle 1994b) each of these steps were described in detail. In the two case studies that follow, we will describe some of the the steps of the methodology in more detail. In the remainder of this section, we will highlight the steps of the phases that protect the simulation modeler/manager from the pitfalls of simulation.

TABLE 1 : PITFALLS OF SIMULATION

Process Related Pitfalls

1. Unclear project objectives
2. Keeping the customer uninformed
3. Not establishing a base for comparison
4. Unrealistic expectations from the study
5. Too much faith in the input data
6. Infrequent reporting and lack of documentation
7. Infrequent customer interaction
8. Inadequate selling of project successes
9. Frequent scope changes
10. Too much faith in the simulation output
11. Inadequate review of the project while it is ongoing
12. Spending more time on the model rather than the problem
13. Not knowing when to stop

Model Related Pitfalls

1. Model assumptions not validated
2. Starting with an overly complex model

3. Losing sight of the implementation issues
4. Using the model sparingly
5. Not understanding the model’s limits

People Related Pitfalls

1. Lack of teamwork
2. Not involving the key decision makers in the project
3. Not knowing and/or listening the customer
4. Providing a small list of alternatives to the customer
5. Being afraid of advocating change

TABLE 2 : SIMULATION METHODOLOGY

| **METHODOLOGY** |
| --- |
| **Phase 1: DEFINE THE PROBLEM** |
| Step 1. Define the objectives of the study. |
| Step 2. List the specific issues to be addressed. |
| Step 3. Determine the boundary or domain of the study. |
| Step 4. Determine the level of detail or proper abstraction level. |
| Step 5. Determine if a simulation model is actually needed; will an analytical method work? |
| Step 6. Estimate the required resources needed to do the study. |
| Step 7. Perform a cost-benefit analysis. |
| Step 8. Create a planning chart of the proposed project. |
| Step 9. Write a formal proposal. |
| **Phase 2: DESIGN THE STUDY** |
| Step 1. Estimate the life cycle of the model. |
| Step 2. List broad assumptions. |
| Step 3. Estimate the number of models required. |
| Step 4. Determine the animation requirements. |
| Step 5. Select the tool. |
| Step 6. Determine the level of data available and what data is needed. |
| Step 7. Determine the human requirements and skill levels. |
| Step 8. Determine the audience (usually more than one level of management). |
| Step 9. Identify the deliverables. |
| Step 10. Determine the priority of this study in relationship to other studies. |
| Step 11. Set milestone dates. |
| Step 12. Write the Project Functional Specifications. |
| **Phase 3: DESIGN THE CONCEPTUAL MODEL** |
| Step 1. Decide on continuous, discrete, or combined modeling. |
| Step 2. Determine the elements that drive the system. |
| Step 3. Determine the entities that should represent the system elements. |
| Step 4. Determine the level of detail needed to describe the system components. |
| Step 5. Determine the graphics requirements of the model. |
| Step 6. Identify the areas that utilize special control logic. |
| Step 7. Determine how to collect statistics in the model and communicate results to the customer. |
| **Phase 4: FORMULATE INPUTS, ASSUMPTIONS, AND PROCESS DEFINITION** |
| Step 1. Specify the operating philosophy of the system. |
| Step 2. Describe the physical constraints of the system. |
| Step 3. Describe the creation and termination of dynamic elements. |
| Step 4. Describe the process in detail. |
| Step 5. Obtain the operation specifications. |
| Step 6. Obtain the material handling specifications. |
| Step 7. List all the assumptions. |
| Step 8. Analyze the input data. |
| Step 9. Specify the runtime parameters. |
| Step 10. Write the detailed Project Functional Specifications. |
| Step 11. Validate the conceptual model. |

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| **Phase 5: BUILD, VERIFY, AND VALIDATE THE SIMULATION MODEL** |
| Step 1. Beware of tool limitations. |
| Step 2. Construct flow diagrams as needed. |
| Step 3. Use modular techniques of model building, verifications, and validation. |
| Step 4. Reuse existing code as much as possible. |
| Step 5. Make verification runs using deterministic data and trace as needed. |
| Step 6. User proper naming conventions. |
| Step 7. Use macros as much as possible. |
| Step 8. Use structured programming techniques. |
| Step 9. Document the model code as model is built. |
| Step 10. Walk through the logic or code with the client. |
| Step 11. Set up official model validation meetings. |
| Step 12. Perform input-output validation. |
| Step 13. Calibrate the model, if necessary. |
| **Phase 6: EXPERIMENT WITH THE MODEL AND LOOK FOR OPPORTUNITIES FOR DESIGN OF EXPERIMENTS** |
| Step 1. Make a pilot run to determine warm-up and steady-state periods. |
| Step 2. Identify the major variables by changing one variable at a time for several scenarios. |
| Step 3. Perform design of experiments if needed. |
| Step 4. Build confidence intervals for output data. |
| Step 5. Apply variance reduction techniques whenever possible. |
| Step 6. Build confidence intervals when comparing alternatives. |
| Step 7. Analyze the results and identify cause-effect relations among input and output variables. |
| **Phase 7: DOCUMENTATION AND PRESENTATION** |
| Step 1. Project Book |
| Step 2. Documentation of model input, code, and output. |
| Step 3. Project Functional Specifications. |
| Step 4. User Manual. |
| Step 5. Maintenance Manual. |
| Step 6. Discussion and explanation of model results. |
| Step 7. Recommendations for further areas of study. |
| Step 8. Final Project Report and presentation. |
| **Phase 8: DEFINE THE MODEL LIFE CYCLE** |
| Step 1. Construct user-friendly model input and output interfaces. |
| Step 2. Determine model and training responsibility. |
| Step 3. Establish data integrity and collection procedures. |
| Step 4. Perform field data validation tests. |

Table 3 below gives the steps of the simulation methodology that protects the project from the pitfalls listed in Table 1.

# TABLE 3 : STEPS OF THE METHODOLOGY PREVENTING EACH PITFALL

| Pitfalls | Methodology Phases | Methodology Steps |
|---|---|---|
| Process Related Pitfalls | | |
| 1 | 1 | 1-3 |
| | 2 | 1 |
| 2 | 2 | 8,9,11,12 |
| | 3 | 7 |
| | 4 | 10,11 |
| | 5 | 10,11 |
| | 7 | 3-6,8 |
| | 8 | 1-2 |
| 3 | 1 | 7 |
| | 2 | 10 |
| | 6 | 1 |
| 4 | 1 | 1-4,8 |
| | 2 | 2,3,7,9-11 |
| | 3 | 7 |
| | 4 | 10,11 |
| | 5 | 10,11 |
| 5 | 2 | 6 |
| | 3 | 7 |
| | 4 | 7,8 |
| | 8 | 3,4 |
| 6 | 2 | 12 |
| | 3 | 7 |
| | 4 | 10 |
| | 5 | 2,6-12 |
| | 7 | 1-8 |
| 7 | 3 | 7 |
| | 4 | 11 |
| | 5 | 10,11 |
| 8 | 6 | 7 |
| | 7 | 6,8 |
| 9 | 2 | 12 |
| | 4 | 10 |
| | 7 | 7 |
| 10 | 5 | 12,13 |
| | 6 | 7 |
| | 7 | 6 |
| 11 | 5 | 10,11 |
| | 6 | 7 |
| 12 | 1 | 3,4,7 |
| | 5 | 4,7 |
| | 6 | 2,3 |
| 13 | 1 | 1-4,8 |
| | 7 | 7 |

| | | |
|---|---|---|
| Model Related Pitfalls | | |
| 1 | 3 | 2-4,6 |
| | 4 | 1-7,10,11 |
| | 5 | 11-13 |
| 2 | 1 | 4 |
| | 2 | 6 |
| | 3 | 4 |
| 3 | 4 | 2,4-6 |
| | 5 | 10 |
| 4 | 6 | 1-7 |
| | 8 | 1,2 |
| 5 | 1 | 3,4 |
| | 2 | 2,6,12 |
| | 4 | 7,10,11 |
| | 5 | 10,11 |
| | 7 | 6 |
| People Related Pitfalls | | |
| 1 | 2 | 7,8 |
| | 3 | 7 |
| | 4 | 11 |
| | 5 | 10,11 |
| | 7 | 6,8 |
| | 8 | 1,2 |
| 2 | 2 | 8 |
| | 3 | 7 |
| | 5 | 11 |
| | 7 | 8 |
| | 8 | 2 |
| 3 | 1 | 1-4 |
| | 2 | 2,4,6,8 |
| | 3 | 2-7 |
| | 4 | 11 |
| | 5 | 10,11,13 |
| 4 | 4 | 9 |
| | 5 | 12 |
| | 6 | 2,3,4,6,7 |
| | 7 | 6,7 |
| | 8 | 1 |
| 5 | 6 | 2,7 |
| | 7 | 6-8 |
| | 8 | 1-3 |

## CASE STUDIES

### Case Study 1: Paint Shop of a Vehicle Assembly Plant

The paint shop involved in this study was part of a vehicle assembly plant. The new paint facility is an upgrade of an existing one which had to be redesigned to increase the throughput of the system. The new paint shop consists of approximately thirty conveyor chains that move jobs from one process to another. The output of the shop goes into an AS/RS from where parts are sent to final assembly line. There are several types of vehicles with different paint requirements.

As the entire plant was undergoing an upgrade, the design team included members from several levels of management and engineering. As the simulation team found earlier in the study, there were significant differences in management’s views of what was important. There were even conflicting views of the objectives of the study. As part of the application of the methodology, the simulation team focused on defining a common set of objectives at a very early stage of the study. Consequently, potential problems regarding the proper usage of simulation were successfully avoided. Furthermore, the model was built and modified with the minimum amount of detail necessary to obtain valid measures of performance. The levels of detail and abstraction were adjusted to the changing needs and objectives of the design process.

As in any design process, the expansion project consisted of several iterations of making and evaluating alternative layout designs. As the design evolved, the simulation model underwent several modifications. Developing and continuously updating project functional specifications helped to establish a common information source for everyone participating in the project. As several groups of people were involved in the process, up-to-date documentation of the model, its assumptions, input data, and current results proved extremely beneficial in eliminating communication problems. Furthermore, periodically updating a designated simulation coordinator at the client site on the status of the project helped to establish and maintain an excellent communication channel. The periodic status reports clarified the status of the project and what the next steps were, and helped minimize frustrations of parties involved in the project.

The results obtained from the simulation study had significant impact on various equipment, layout, and scheduling issues. Determinations of the size of banks of buffer conveyors, adjustment of the speed of several production conveyors, and establishment of job sequencing rules were the most important results of the study. The simulation model was also updated for the final version of the conveyor controller logic and turned over to the client with a user-friendly front-end to be used by the engineers as an on-going decision and training tool.

When the primary objective of the study was the verification of the throughput rates, control logic of the conveyor segments, and proper sizing of the buffers, a detailed model was used that included the exact length of conveyors with their speed-up and slow-down segments, control logic for turn tables, repair rates for different types of repairs, etc.  On the other hand, when the objective of the study changed to optimize the sequencing of different types of vehicles at the beginning of the paint shop so that the size of the resequencing buffer at the end of the paint shop was minimized, a separate model was developed that ignored the details of equipment but emphasized the sequencing and repairs of different vehicle types in the paint shop.

| Guidelines Assuring Success: | Set clear project objectives |
|---|---|
| | Keep the customer informed |
| | Report frequently |
| | Document |
| | Get customer involved |
| | Freeze scope changes |
| | Start simple |
| | Understand the model's limits |

**Case Study 2: Applying the Steps of Phase 1: Define the Problem**

A large manufacturing firm wanted to build a set of parts for a specialized vehicle facility.  These sets were made up of either two or four parts.  Each part itself was made up of nine to eleven subparts.  All the parts including the subparts were to be manufactured at the facility.  The following tasks were to be performed by the engineers for this project:

1. Design the patterns for the parts
2. Design the patterns for the dies that make the parts
3. Make the dies
4. Stamp the parts
5. Assemble the parts into the end product

The parts and dies follow complex routings.  At each step of the routing, different tools, operators, and setups are needed at each process station. Each group of parts and dies has a different processing time and depends on other parts and dies finishing before them to start their own processing.

One of the largest of all pitfalls facing a simulation engineer is the proper problem definition and Phase I of the simulation methodology addresses this issue.  There are several steps as given in Table 2 in this phase of a simulation study.

The first step was to define and agree on the objectives of the study. In this case, the main objective was to verify that there was enough resource capacity in the current system to do the work. Specifically, the firm wanted to know if there were enough machines to build the parts and dies needed for the final products. The objective was also to identify the bottleneck operation/resource in the system.

The second step of the study was to determine the specific issues to be addressed in the study. These included the maximum capacity of the system, the utilization of the station families for each processing area, and the identification of the governing operation in the facility for the product mix in question. The measures to be used in the study were identified as throughput in jobs per hour and utilization of the station families as a percentage of available working hours.

The third step was to determine the boundary of the study. In this case, the boundaries would apply to those facilities needed to make the parts, subparts and dies. The suppliers that produced some of the components of the parts were not explicitly considered in the study. The supplied components were assumed to arrive at regular intervals from a “blackbox” external process.

The fourth step in defining the problem was to determine the level of detail needed in the study. In this particular case, it would have been easy to get bogged down in too much detail. As mentioned earlier, the major assemblies required nine to eleven subparts and one had to consider all the dies that went into making them. In addition, the plant had a production goal of about 3,000 major assemblies in one production year. This would correspond to about 30,000 parts in one production year. With that many parts, it would have been inefficient to build a model with extensive graphics or load representation. In this case, the model was designed to consider the machines, assemblies, dies, subparts, routings, and manpower. However, to simplify things, these entities were not explicitly modeled in detail but rather as counters and variables.

The fifth step was to determine the method of analysis to be used in the study. In this case, two methods were used. One method was to use static spreadsheet calculations and the other was to use the AutoSched[i] scheduling package. The two approaches were used concurrently to provide the most accurate and quickest response to the questions presented in the study. Static analysis is nothing more than a spreadsheet analysis of the data incorporated into simulation. This analysis is useful in pointing out areas of gross significance. It does not take into account the dynamic process issues that simulation considers such as competition for resources at different times, scheduling effects, and blocking effects. This dual approach helped the engineers to identify the potential bottleneck operations in the system. Simulation was then used to narrow down to these processes and use more efficient scheduling techniques at these processes.

The sixth step was to determine the resources required to do the study. The complexity of considering different combinations of parts, subparts, machines, manpower, and dies and the respective options available for scheduling, pointed out the need for a workstation to run the model of such a system and a modeler trained to work effectively using such a system.

The last three steps were more administrative. These require the engineer to do a cost-benefit analysis, create a planning chart for the project, and write a formal proposal for the project. These can be the deciding factors in a successful simulation. For example, in the case study, the financial information was readily available. It was determined that, based on the original plans, the plant was supposed to spend millions of dollars to expand the facility but simulation study showed that this investment was not going to meet the target production goals. The capital investment was going to be made in the wrong equipment. The planning chart was also useful in presenting the milestones of the project. It gave the engineers a plan for progress meetings and information requirements and availability at different phases of the project. Lastly, the written proposal was important in that it established and froze the objectives and boundary of the study. It allowed for a successful simulation project because all parties involved in the study knew what to expect from the analysis.

In conclusion, the nine step approach in Phase I (see Table 2) for defining the project scope is extremely useful. These steps are also useful to teach new simulation engineers how to manage simulation projects that are external or internal to a company right from the first day of a project.

## CONCLUSIONS

An examination of the phases and steps of the methodology indicates that client involvement is perhaps the most important overall recommendation. Being aware of the needs and the objectives of the clients, getting their feedback and approval on the model, updating them on the status of the study, and providing them clearly stated results are crucially important for the success of any simulation study. Adherence to the methodology by paying close attention to each step ensures that those general guidelines are met. Finally, it can be recommended that checklists representing the steps of all phases of the methodology be used throughout any simulation project by large or small simulation companies and service groups.

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[i] AutoSched is a registered trademark of AutoSimulations, Inc.