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SECRETS OF SUCCESSFUL SIMULATION PROJECTS

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ABSTRACT

The purpose of this paper is to describe how a simulation project should be performed in order to ensure a successful outcome. This involves skills in both simulation and project management. The paper concentrates on the process of performing a simulation project rather than specific methods required during the course of a project. An overview of a simulation project is given before discussing in more detail the four main phases of a project: problem definition, model building and testing, experimentation, and project completion.

1 INTRODUCTION

The purpose of this paper is to describe how a simulation project should be performed in order to ensure a successful outcome. Firstly it is important to understand what is meant by success in the context of a simulation project. Here a successful project is considered to be one where the results and recommendations are accepted by the customer. Since the simulation modeller rarely has much influence over whether those results and recommendations are actually implemented this definition of success does not include implementation. However, there is little doubt that getting the results accepted is a significant and necessary step towards getting the results implemented (Schultz and Slevin 1975).

Acceptability is derived from two main concepts: a valid simulation model, which Law and Kelton (1991) define as a model that is an accurate representation of the actual system being modelled; and a credible study, which McLeod (1982) defines as 'the quality or power of inspiring belief'. Therefore, throughout a simulation project the aim should be to secure both of these which requires skills in simulation and project management. This paper aims to briefly describe how this might be achieved.

The paper starts with an overview of a simulation study which is then followed by a more detailed discussion of each phase in a simulation project. This discussion concentrates on a description of the processes involved rather than a detailed description of the specific methods and techniques required at each stage.

2 AN OVERVIEW OF THE PROCESSES IN A SIMULATION PROJECT

There are four main phases in a simulation project (Figure 1).

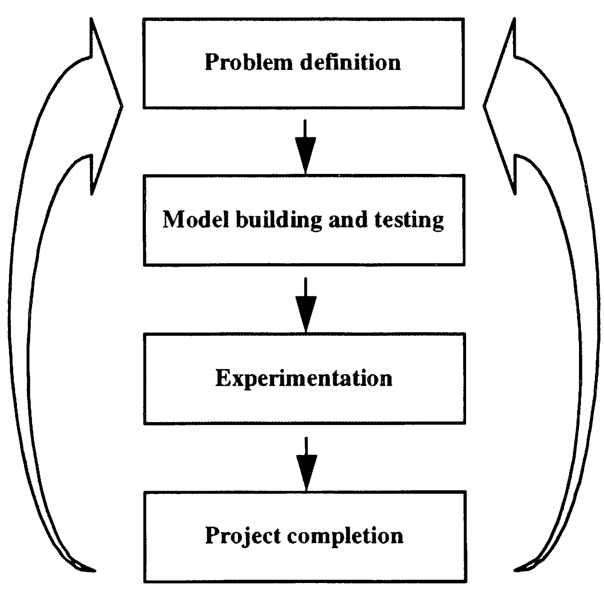

Figure 1: Simulation Projects: an Overview (Source: Robinson 1994a)

The initial phase, problem definition, consists of understanding the problem to be tackled and gathering all the necessary information. The model is then built and tested before experimentation begins. Having completed experimentation the results need to be communicated and the project needs to be brought to a satisfactory conclusion.

Although these four main phases have been shown in a linear fashion a project is performed in anything but a strict sequential manner. The additional arrows aim to demonstrate the iterative nature of the process. A project certainly begins with problem definition and ends with project completion but the movement is not always downwards. For example, during experimentation an issue might be identified that had previously not been considered, therefore it is necessary to redefine the problem and change the model before continuing with further experimentation. There are many of these potential feedback loops and it is probably a mistake to try and identify each one; it is simply best to recognise that at any point in a project some form of iteration may be necessary. Modern interactive simulation software enhances this iterative process by enabling models to be built in stages.

In terms of time-scales, it is not easy to give general guidance on how long a simulation project will take (it could be anything from a day to a number of years), however, it is useful to consider the proportion of time that needs to be devoted to each phase. Often people think in terms of only model building and do not allow enough time for the other, vital, processes involved. Figure 2 outlines the proportion of a project that will probably be devoted to each phase. The arrows show that each phase may take up a greater or lesser proportion of the project. It is notable that model building, including testing, is only a third of the total project.

What now follows is a more detailed description of the four phases in a simulation study.

3 PHASE ONE: PROBLEM DEFINITION

The problem definition phase consists of the following stages:

- identify the problem and set the objectives
- define the experimental factors and reports
- determine the scope and level of the model
- collect and analyse the data
- provide a project specification

In a similar manner to the overall project these five stages are also performed in an iterative manner. Each of these stages is now considered in turn.

3.1 Identify the Problem and Set the Objectives

Without a clear set of objectives it is almost impossible for a project to succeed. The objectives set the direction for the project and demonstrate an understanding of the problem to be tackled. Through discussions with the customer it is important to develop an understanding of the system to be modelled and the problems that are to be tackled. The customer should be asked to identify their objectives for the project. Since customers are often relative novices at simulation there may be potential objectives that they do not identify, therefore,

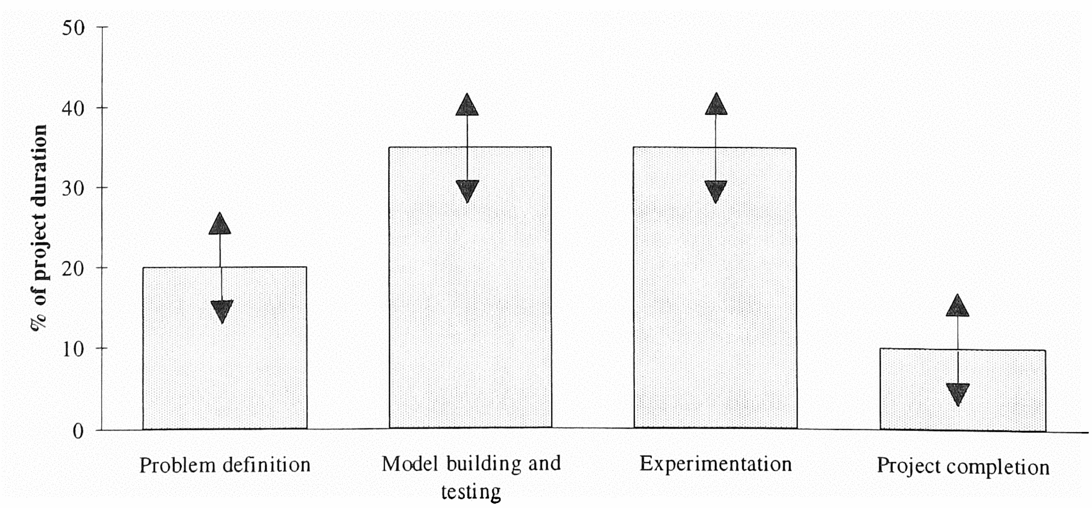

Figure 2: Project Time-scales: a Percentage Breakdown (Source: Robinson 1994a)

the simulation modeller should be ready to suggest additional objectives. No objective should be set in stone and throughout the project flexibility must be built-in so change can be accommodated.

3.2 Define Experimental Factors and Reports

In essence a simulation model takes a set of inputs (experimental factors), imitates their effect on a system and provides reports showing the outcome (outputs or responses), Figure 3.

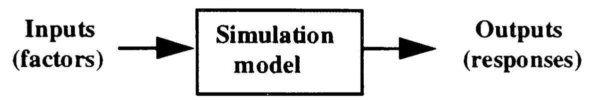

Figure 3: The Basis of Simulation Modelling

Before deciding how to build the simulation model it is important to know what are the likely experimental factors and reports. Without defining these first it is impossible to be sure that the model will be capable of accepting the required inputs and providing the necessary reports.

The objectives of the project are vital in defining the experimental factors and reports. From the objectives it should be possible to identify the likely factors, for instance, the purpose of modelling a manufacturing plant may be to increase throughput. The experimental factors are therefore likely to be elements such as machine cycle times, buffer sizes and the number of operators, all of which directly affect throughput. Similarly the reports should provide statistics which will enable the modeller to check whether the objectives have been achieved; in this example throughput obviously has to be reported, but also aspects such as machine and operator utilisation.

3.3 Determine the Scope and Level of the Model

This stage is also known as conceptual modelling. Here the elements that need to be included in the simulation model are determined. The 'scope' is the breadth of the model, what should be included; the 'level' is the depth of detail required for each element in the model. The basic rule is to only include the minimum scope and level of detail required to meet the objectives of the project. If excessive detail is included then a significant amount of time can be wasted collecting data and building the model. Obviously if the model is not detailed enough then the results may not be sufficiently accurate. Getting the scope and level of detail right is more of an art than a science. The key thing is that the model is able to accept the experimental factors and provide the reports identified in the previous stage. Beyond this, the model needs to be sufficiently accurate to meet the objectives of the project (Robinson 1994b).

At this stage the model simply consists of a list of elements and the level of detail required for each one. Therefore, conceptual modelling is largely software independent, the actual details of the simulation package not having to be considered until the second phase of the project, model building and testing.

3.4 Collect and Analyse the Data

Data are required not only to build the simulation model but also to test its validity. The data requirements can quickly be identified from the elements in the conceptual model, the level of detail showing exactly what data are required for each element. Data collection and analysis may take some time and therefore it is often performed in parallel with the other modelling activities.

Not all data are readily available, there being three basic categories of data:

- category A: available
- category B: not available but collectable
- category C: not available and not collectable

Data in category C obviously present the main difficulty. These data can be dealt with by estimating their values. However, it is unreasonable to expect customers to accept results based on estimated data, so having estimated the data a useful technique is to perform sensitivity analysis on these data to establish the sensitivity of the results to their accuracy.

3.5 Provide a Project Specification

Before progressing to model building it is important to check that the problem has been properly understood and that the modelling approach is correct. A useful means for this is to write, or sometimes verbally communicate, a project specification. This document outlines the problem being tackled, the objectives of the project, the model (scope and level of detail, assumptions, experimental factors and reports), data requirements, time-scale and milestones, and estimated cost (where applicable). Opportunity should then be given for the customers to give feedback on your proposed approach.

It should not be assumed that the project specification will remain unchanged as the project progresses. Aspects may have been omitted from the original specification, changes may have occurred in the real world system and an increased understanding as the project progresses could all lead to changes in the specification. However, restraint needs to be exerted over these changes in order to prevent project time-scales from slipping; a change control mechanism should be put in place. This could consist of a change to specification form that outlines the change and its effect on the quality of the model, project timing and cost. Agreement to this change should then be obtained before implementing it.

4 PHASE TWO: MODEL BUILDING AND TESTING

The model building and testing phase consists of the following stages:

- structure the model
- build the model: coding, documenting, verifying
- validate the model

Each of these stages is now discussed.

4.1 Structure the Model

Prior to entering the model into the computer the structure is designed, probably on paper; for the first time the model becomes software specific. This step ensures that, before the simulation software is used, the best method of modelling is considered. It also provides some useful documentation once the model is built. Designing the model on paper first can save time by making sure that the structure is properly thought through before entering the model into the computer.

4.2 Build the Model

There are three distinct aspects to model building. Model coding involves entering the model into the computer using a software package or language. Coding is best performed in small iterative steps breaking the model down into its constituent parts. For each section the basic detail is entered before gradually increasing the detail to the desired level. Many software packages enable the modeller to run the simulation at any point in order to see the latest model development in action. This enables continuous testing of the code (verification).

Secondly, documentation needs to be continuously updated during the model building stage. If this is left to the end it is probable that much of the detail will have been forgotten, and likely that the documentation will not get done at all when the modeller is swamped by other 'more important' tasks.

The final part of model building is verifying the model code. This process is integral to model coding and documentation and involves checking that the code is correct. The modeller needs to ensure that each element in the model behaves in the intended manner when the model runs. This stage is very much analogous to debugging code in computer programming applications.

4.3 Validate the Model

The final step in model building and testing is validation. Experimentation must not begin until the modeller, and customer, is satisfied that the model is valid. This requires that the simulation is an accurate representation of the real world system that is being modelled. It is also important to check that the model can meet the objectives of the project for which it is being used.

Space does not allow a full discussion on the wide variety of methods available for validating a model. Broadly, the most common techniques fall into three categories:

- face validity: on the surface the model appears to be reasonable
- comparison with the real system: checking the model against data from the real system
- comparison with other models: checking the simulation against data from other models, for example, engineering calculations

Sargent (1992) and Balci (1994) give detailed reviews of validation techniques in simulation.

5 PHASE THREE: EXPERIMENTATION

The experimentation phase consists of the following stages:

- performing experiments: determine the warm-up, run-length and replications; select experiments
- analyse the results and draw conclusions

Proposed methods for achieving the projects objectives are tested and the results are analysed. During this analysis new ideas are often formed and further experiments are carried out. Therefore, like all the other phases in a simulation project, experimentation is carried out in an iterative manner moving between selecting and performing experiments, and analysis of the results.

5.1 Perform Experiments

Various issues have to be considered when performing simulation experiments. Space does not allow a detailed discussion of the techniques for resolving these, however, a brief outline of the main issues is given below. For a more detailed discussion see Law and Kelton (1991) and Robinson (1994a).

The first issue is that of a warm-up period. When starting to collect results from a model it is important that the model is in a realistic condition, otherwise the results will be biased. However, many models do not start in a realistic state. For example, a model of a manufacturing plant will normally begin running with no parts in the system. This is not, in most cases, a realistic condition. The problem is resolved by allowing the model to run for a 'warm-up' period before collecting statistics. Various techniques are available for selecting a warm-up period. An alternative approach is to set up 'starting conditions' in the model; the model is put into realistic state at the beginning of a run. The simplest instance of a starting condition is a model of a service system, such as a bank, where an empty state is a realistic condition at the start of a day's trading.

The second issue is deciding how long a model run should be. Some models have a natural termination point (terminating simulation), for instance, a shop closes at the end of the day, while others have no such termination point (non-terminating simulation). For non-terminating simulations the basic rule is the longer the run, the better. Robinson (1995) describes a method for selecting the run-length for non-terminating simulations.

Third, it is necessary to decide how many replications to perform. A single run of a simulation model is a replication. Further replications are performed by changing the random numbers generated during the model run and performing further runs with the same scenario. Performing multiple replications is basically a means for increasing the sample size of the results collected and so improving confidence. Law and Kelton (1991) recommend that at least 3 to 5 replications are performed. More advanced techniques are available for selecting the number of replications.

The final issue in experimentation is selecting the actual experiments that need to be performed. This is trivial where the model has been built to compare a few alternative scenarios. It is more complex when the brief is to search for some target (for example, a throughput or customer service target) or optimum without defining the means for achieving that. In other words a number of variables could be changed in tandem in order to achieve the desired result and the modeller has to determine the best means for obtaining this. Very quickly the number of simulation runs could become infeasible within the time-scales of the project. If, for instance, there were 4 experimental factors each of which could take on three different values (levels) then a total of 81 scenarios would need to be tested.

Experimental design techniques are available for reducing the number of experiments required. These are beyond the scope of this paper, however, Law and Kelton (1991) provide a useful starting point for learning about these techniques while Robinson (1994a) takes a pragmatic approach to experiment selection.

5.2 Analyse the Results and Draw Conclusions

The purpose of analysing the results is to check the extent to which the objectives of the project have been achieved. During this stage it must be remembered that the results are only estimates of the true values. Consequently, confidence intervals and hypothesis tests are a useful means for testing the confidence that can be placed in the results. The variability in the results is also important. Two scenarios may give the same mean but one may be based on a much wider distribution of observations. It is probable that the narrower distribution would be preferred.

When drawing conclusions and making recommendations it should be remembered that simulation is a decision support tool. Wider influences from the organisational context as a whole, for instance managerial support, should also be considered before drawing up a list of recommendations.

6 PHASE FOUR: PROJECT COMPLETION AND IMPLEMENTATION

The fourth and final phase of the project consists of the following steps:

- communicate the results
- complete the documentation
- review the project
- perform further simulation work

This represents a vital but often overlooked phase in a project. If a project is not successfully closed then the customers may let this reflect on their view of the project as a whole.

6.1 Communicate the Results

The results need to be communicated in written and/or verbal form to all parties that have a vested interest in the project. In such a report it is probably worth reiterating the problem that was being tackled, the objectives and an outline of the model before going on to describe the experimentation, results, conclusions and recommendations. Communication is not complete until the recipients have at least understood what is being said and preferably agree with the recommendations.

6.2 Complete the Documentation

Various documents are created through the course of a project, for example:

- project specification
- model documentation
- user documentation
- final report
- minutes of project team meetings
- project review

At this point these should be completed and made ready for future reference. The model and the results can then be re-used more easily.

6.3 Review the Project

It is useful to review, with the customer, how the project went. This gives opportunity for learning on behalf of the modeller and the customer. The discussion should cover aspects such as what was done well, what could have been done better, and how it could be done better next time, with the aim of identifying specific actions for improvement.

6.4 Perform Further Simulation Work

Having completed the project further simulation work may be possible. This could be a case of keeping the model up-to-date enabling continued analysis of the facility in line with its current status. This occurs, for example, when the model continues to be used throughout implementation. A procedure needs to be put in place to ensure that the modeller is notified of any changes to the design of the real facility so these can be incorporated in the model.

Another requirement might be a further phase of the same project. Further phases of work may have been identified either at the beginning of a project or during a later phase. The opportunity now exists to embark on the next phase of the work.

Finally, if a project has been successful this increases the chance that a customer will ask for another project to be carried out. The modeller should look for further opportunities to apply simulation.

7 CONCLUSION

Although this paper only describes the project to the point of accepting the results, it must not be forgotten that if those results are not implemented then the project has probably been a waste of time. Having obtained acceptance a sensible strategy for implementing the results needs to be put in place. This requires an implementation project in its own right which will ensure that the results are properly implemented and that the outcome is monitored.

What has been outlined is a 'model' project. The sequence of events and the details of each phase need to be adapted to individual circumstances. However, this framework provides a useful basis from which to work.

The approach could be considered a traditional project approach. Although modern simulation software enables models to be built in an interactive fashion, this does not dispense with the need for a sound methodology; the problem still needs to be defined, the model still needs to be built and tested, experiments still have to be performed, and the results still have to be communicated. All this needs to be carried out in an ordered fashion if a project is to succeed.

REFERENCES

Balci, O. 1994. Validation, Verification, and Testing Techniques Throughout the Life Cycle of a Simulation Study. Technical Report TR 94-08, Department of Computer Science, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Law, A. and W. Kelton. 1991. *Simulation Modeling and Analysis, 2nd ed.* New York: McGraw-Hill.

McLeod, J. 1982. Computer Modeling and Simulation: Principles of Good Practice. *Simulation Series* 10 (2). The Society for Computer Simulation, San Diego, CA.

Robinson, S. 1994a. *Successful Simulation: A Practical Approach to Simulation Projects.* Maidenhead, UK: McGraw-Hill.

Robinson, S. 1994b. Simulation Projects: Building the Right Conceptual Model. *Industrial Engineering* 26 (9): 34-36.

Robinson, S. 1995. An Heuristic Technique for Selecting the Run-length of Non-terminating Steady-state Simulations. To appear in *Simulation* 65 (3).

Sargent, R. G. 1992. Validation and Verification of Simulation Models. In *Proceedings of the 1992 Winter Simulation Conference*, eds. J. J. Swain, D. Goldsman, R. C. Crain and J. R. Wilson, 104-114. IEEE, Piscataway, NJ.

Schultz, R. L. and D. P. Slevin. 1975. *Implementing Operations Research-Management Science.* New York: Elsevier.

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