

## Steps in Simulation study:

Figure 1 is a schematic of a simulation study. In a simulation study, human decision making is required at all stages, namely, model development, experiment design, output analysis, conclusion formulation, and making decisions to alter the system under study. The only stage where human intervention is not required is the running of the simulations.

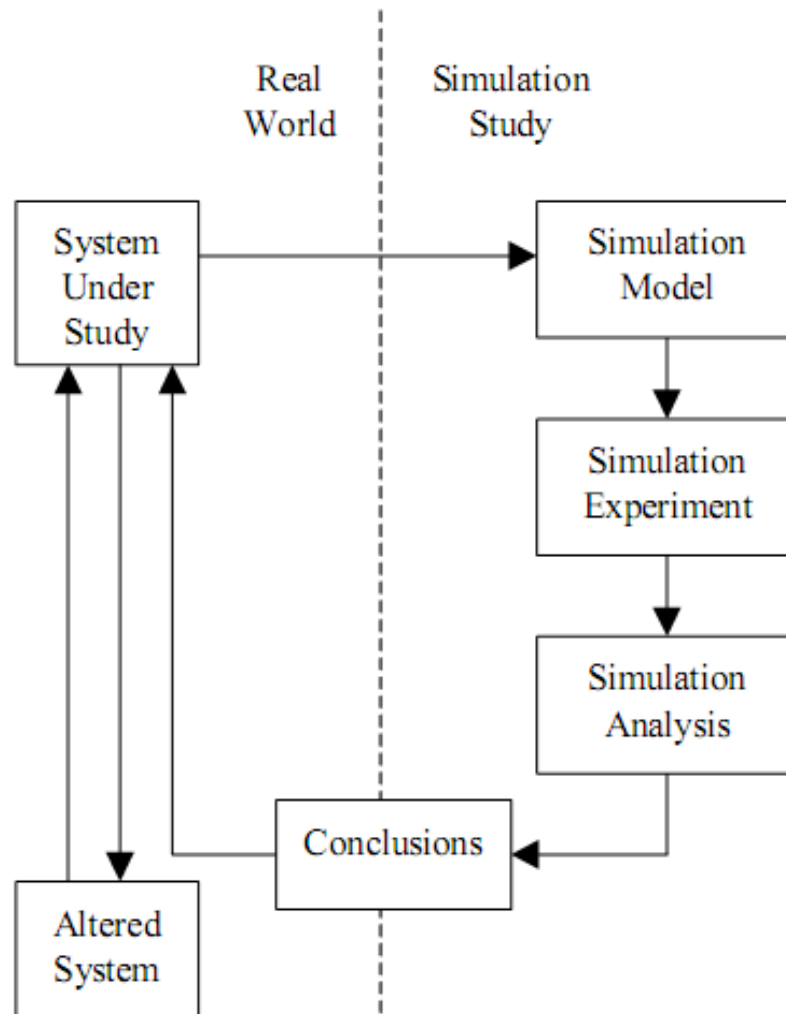


Figure 1: Simulation Study Schematic

The steps involved in developing a simulation model, designing a simulation experiment, and performing simulation analysis are:

- Step 1. Identify the problem.
- Step 2. Formulate the problem.
- Step 3. Collect and process real system data.
- Step 4. Formulate and develop a model.

- Step 5. Validate the model.
- Step 6. Document model for future use.
- Step 7. Select appropriate experimental design.
- Step 8. Establish experimental conditions for runs.
- Step 9. Perform simulation runs.
- Step 10. Interpret and present results.
- Step 11. Recommend further sequence of action.

Although this is a logical ordering of steps in a simulation study, much iteration at various sub-stages may be required before the objectives of a simulation study are achieved. Not all the steps may be possible and/or required. On the other hand, additional steps may have to be performed.

### **How to Develop a Simulation Model?**

Simulation modeling includes the following steps:

#### *Step 1. Identify the problem.*

Enumerate problems with an existing system. Produce requirements for a proposed system.

#### *Step 2. Formulate the problem.*

Select the bounds of the system, the problem or a part thereof, to be studied. Define overall objective of the study and a few specific issues to be addressed. Define performance measures. Identify, briefly at this stage, the configurations of interest and formulate hypotheses about system performance. Decide the time frame of the study, i.e., will the model be used for a one-time decision (e.g., capital expenditure) or over a period of time on a regular basis (e.g., air traffic scheduling). Identify the end user of the simulation model, e.g., corporate management versus a production supervisor. Problems must be formulated as possible.

#### *Step 3. Collect and process real system data.*

Collect data on system specifications (e.g., bandwidth for a communication network), input variables, as well as performance of the existing system. Identify sources of randomness in the system, i.e., the stochastic input variables. Select an appropriate input probability distribution for each stochastic input variable and estimate corresponding parameter(s).

*Step 4. Formulate and develop a model.*

Develop schematics and network diagrams of the system (How do entities flow through the system?). Translate these conceptual models to simulation software acceptable form. Verify that the simulation model executes as intended. Verification techniques include traces, varying input parameters over their acceptable range and checking the output, substituting constants for random variables and manually checking results, and animation.

*Step 5. Validate the model.*

Compare the model's performance under known conditions with the performance of the real system. Perform statistical inference tests and get the model examined by system experts. Assess the confidence that the end user places on the model and address problems if any.

*Step 6. Document model for future use.*

Document objectives, assumptions and input variables in detail.

**How to Design a Simulation Experiment?**

Simulation experiment is a test or a series of tests in which meaningful changes are made to the input variables of a simulation model so that we may observe and identify the reasons for changes in the performance measures. Design of a simulation experiment involves answering the question: what data need to be obtained, in what form, and how much? The following steps illustrate the process of designing a simulation experiment.

*Step 7. Select appropriate experimental design.*

Select a performance measure, a few input variables that are likely to influence it, and the levels of each input variable.

*Step 8. Establish experimental conditions for runs.*

Select the run length. Select appropriate starting conditions (e.g., empty and idle, five customers in queue at time 0). Decide the number of independent runs - each run uses a different random number stream and the same starting conditions by considering output data sample size.

*Step 9. Perform simulation runs.*

Perform runs according to steps 7-8 above.

### How to Perform Simulation Analysis?

Analysis of simulation output data consists of the following steps.

*Step 10. Interpret and present results.*

Compute numerical estimates (e.g., mean, confidence intervals) of the desired performance measure for each configuration of interest. Test hypotheses about system performance. Construct graphical displays (e.g., pie charts, histograms) of the output data. Document results and conclusions.

*Step 11. Recommend further sequence of action.*

This may include further experiments to increase the accuracy and reduce the bias of estimators, to perform sensitivity analyses, etc.

### An Example

A machine shop contains two drills, one straightener, and one finishing operator. Figure 2 shows a schematic of the machine shop. Two types of parts enter the machine shop. Type 1 parts require drilling, straightening, and finishing in sequence. Type 2 parts require only drilling and finishing. The frequency of arrival and the time to be routed to the drilling area are deterministic for both types of parts.

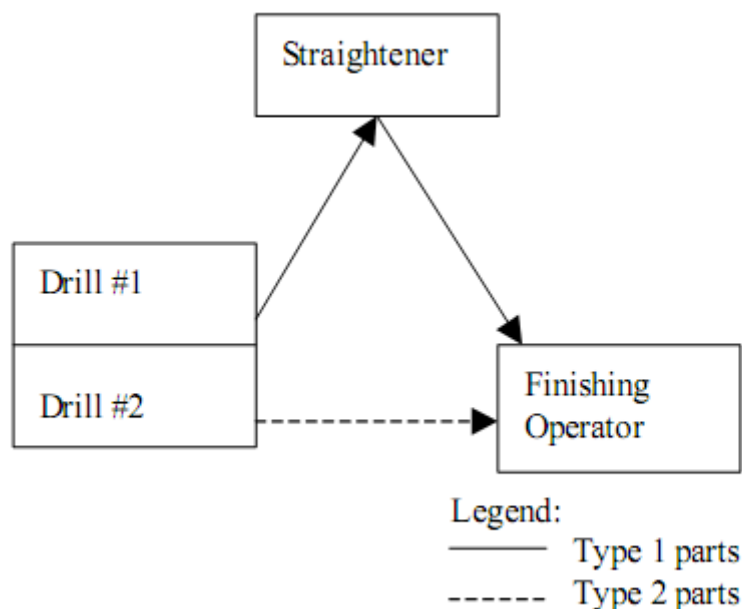


Figure 2: Schematic of the Machine Shop

*Step 1. Identify the problem.*

The utilization of drills, straightener, and finishing operator needs to be assessed. In addition, the following modification to the original system is of interest: the frequency of arrival of both parts is exponential with the same respective means as in the original system.

*Step 2. Formulate the problem.*

The objective is to obtain the utilization of drills, straightener, and finishing operator for the *original system* and the *modification*. The assumptions include:

- The two drills are identical
- There is no material handling time between the three operations.
- Machine availability implies operator availability.
- Parts are processed on a FIFO basis.
- All times are in minutes.

*Step 3. Collect and process real system data.*

At the job shop, a Type 1 part arrives every 30 minutes, and a Type 2 part arrives every 20 minutes. It takes 2 minutes to route a Type 1 part and 10 minutes to route a Type 2 part to the drilling area. Parts wait in a queue till one of the two drilling machines becomes available.

After drilling, Type 1 parts are routed to the straightener and Type 2 parts are routed to the finishing operator. After straightening, Type 1 parts are routed to the finishing operator.

The operation times for either part were determined to be as follows. Drilling time is normally distributed with mean 10.0 and standard deviation 1.0. Straightening time is exponentially distributed with a mean of 15.0. Finishing requires 5 minutes per part.

*Step 4. Formulate and develop a model.*

A model of the system and the modification was developed using a simulation package. A trace verified that the parts flowed through the job shop as expected.

*Step 5. Validate the model.*

The utilization for a sufficiently long run of the original system was judged to be reasonable by the machine shop operators.

*Step 6. Document model for future use.*

The models of the original system and the modification were documented as thoroughly as possible.

*Step 7. Select appropriate experimental design.*

The original system and the modification described above were studied.

*Step 8. Establish experimental conditions for runs.*

Each model was run three times for 4000 minutes and statistical registers were cleared at time 1000, so the statistics below were collected on the time interval [1000, 4000]. At the beginning of a simulation run, there were no parts in the machine shop.

*Step 9. Perform simulation runs.*

Runs were performed as specified in Step 8 above.

*Step 10. Interpret and present results.*

Mean utilization represents the fraction of time a server is busy, i.e., busy time/total time. Furthermore, the average utilization output for drilling must be divided by the number of drills in order to get the utilization per drill. Each drill is busy about 40% of the time and straightening and finishing operations are busy about half the time. The average utilization did not change substantially between the original system and the modification; the standard deviation of the drilling operation seems to have increased because of the increased randomness in the modification.

*Step 11. Recommend further sequence of action.*

Other performance measures of interest may be: throughput of parts for the system, mean time in system for both types of parts, average and maximum queue lengths for each operation. Other modifications of interest may be: the flow of parts to the machine shop doubles, the finishing operation will be repeated for 10% of the products on a probabilistic basis.