UNIT 1. INTRODUCTION TO SIMULATION

1.1 INTRODUCTION

A ***Simulation*** is the imitation of the operation of a real-world process/system over time. It involves the generation and observation of an artificial history of a system and then to draw inferences about characteristics of real system.

The behavior of a system is studied by developing a ***simulation model***. This model contains a set of assumptions about the operation of the system. These assumptions are expressed in mathematical/logical/symbolic relationships between the entities/objects of the system. Once developed and validated, a model can be used to investigate variety of questions about the real-world system. Thus, simulation modeling can be used as –

- an analysis tool for predicting the effect of changes to existing systems
- a design tool to predict the performance of new systems under different circumstances

A simulation model can be developed that can be solved by mathematical methods. The solution consists of one or more numerical parameters, called as *measures of performance* of the system. But, many real-world systems are complex and cannot be solved mathematically. In such cases, numerical, computer-based simulation is used to imitate the behavior of the system. This simulation-generated data is used to estimate the measures of performance of the system.

1.2 WHEN SIMULATION IS THE APPROPRIATE TOOL

There are many special-purpose simulation languages, methodologies and tools are available at a less cost and with high computing capability. When to use which tool is also being discussed over the time. Simulation can be used for following purposes:

- Simulation facilitates the study and experiment of a complex system.
- Informational, organizational and environmental changes can be simulated and the effect of these alterations on the model‘s behavior can be observed.
- The knowledge gained by designing a simulation model will be useful to suggest the improvement in the system.
- By changing simulation inputs and observing the resulting outputs, following information about variables can be gathered:
  - which variables are most important and
  - how variables interact
- Simulation can be used
  - as an instructive device to support and verify analytic solution methodologies
  - to experiment with new designs or policies prior to implementation, so as to prepare for future course of action.
  - to simulate different capabilities of a machine and to determine its requirements.
- Simulation models designed for training, allow learning without the cost and disruption of on-the-job learning
- Animation shows a system in simulated operation so that the plan can be visualized.

- Many modern systems like water fabrication plant, service organization etc. are very complex and can be treated only through simulation.

1.3 WHEN SIMULATION IS NOT APPROPRIATE

Simulation should not be used when

- the problem can be solved just by using common sense.
- the problem can be solved analytically.
- it is easy to perform direct experiments.
- the costs exceeds savings.
- the resources or time are not available.
- there is no enough data
- there is no enough time and/or manpower to verify and validate the model
- there is unreasonable expectations (like too much, too soon)
- the system behavior is too complex or cannot be defined.

1.4 ADVANTAGES AND DISADVANTAGES OF SIMULATION

As simulation depicts the working of real-systems in the design stage itself, it attracts the clients. Moreover, simulation systems are *run* rather than being *solved.* Hence, the behavior of proposed system can be recorded and characteristics are observed. Finally, a good model can be implemented.

Some of the advantages of simulation are:

- New policies, operating procedures, decision rules, information flow, etc can be explored without disrupting the ongoing operations of the real system.
- New hardware designs, physical layouts, transportation systems etc. can be tested without committing resources for their acquisition.
- Hypotheses about how or why certain phenomena occur can be tested for feasibility.
- Time can be compressed or expanded allowing for a speedup or slowdown of the phenomena under investigation.
- Insight can be obtained about the interaction of variables.
- Insight can be obtained about the importance of variables to the performance of the system.
- Bottleneck analysis can be performed indication where work-in process, information materials and so on are being excessively delayed.
- A simulation study can help in understanding how the system operates rather than how individuals think the system operates.
- “what-if” questions can be answered. Useful in the design of new systems.

Some disadvantages are:

- Model building requires special training. This needs time and experience. There may be more than one model developed by different people and it may become difficult to choose the one among them.
- Simulation results may be difficult to interpret. Most of the simulation outputs are random variables. So, it will be hard to distinguish whether an observation is the result of system interrelationships or of randomness.

- Simulation modeling and analysis can be time consuming and expensive.
- Simulation is used in some cases when an analytical solution is possible or even preferable.

1.5 AREAS OF APPLICATION

Applications of simulation are vast. Few have been listed here:

- **Manufacturing Applications**
    - Dynamic modeling of continuous manufacturing systems, using analogies to electrical systems
    - Benchmarking of a stochastic production planning model in a simulation test bed
    - Paint line color change reduction in automobile assembly
    - Modeling for quality and productivity in steel cord manufacturing
    - Shared resource capacity analysis in biotech manufacturing
    - Neutral information model for simulating machine shop operations
- **Wafer Fabrication**
    - A paradigm shift in assigning lots to tools
    - Scheduling a multi-chip package assembly line with re-entrant processes
    - Execution level capacity allocation decisions for assembly-test facilities
    - Managing cycle time with the help of loop control
- **Business Processing**
    - A new policy for the service request assignment problem
    - Process execution monitoring and adjustment schemes
    - In-store merchandizing of retail stores
    - Sales forecasting for retail small stores
- **Construction Engineering and Project Management**
    - Impact of multitasking and merge bias on procurement of complex equipment
    - Application of lean concepts and simulation for drainage operations maintenance crews
    - Building a virtual shop model for steel fabrication
    - Simulation of the residential lumber supply chain
- **Logistics, Transportation and Distribution**
    - Inventory analysis in a server-computer manufacturing environment
    - Semiconductor supply-network simulation
    - Analysis of international departure passenger flows in an airport terminal
    - Application of discrete simulation techniques to liquid natural gas supply chains
    - Online simulation of pedestrian flow in public buildings
- **Military Applications**
    - Frequency-based design for terminating simulations: A peace-enforcement example
    - A multi-based framework for supporting military-based interactive simulations in 3D environments
    - Specifying the behavior of computer-generated forces without programming
    - Fidelity and validity Issues of human behavioral representation

- Assessing technology effects on human performance through trade-space development and evaluation
- Impact of an automatic logistics system on the sortie-generation process
- Research plan development for modeling and simulation of military operations in urban terrain

- **Heath Care**
  - Modeling front office and patient care in ambulatory health care practices
  - Evaluation of hospital operations between the emergency department and a medical telemetry unit
  - Estimating maximum capacity in an emergency room
  - Reducing the length of stay in an emergency department
  - Simulating six-sigma improvement ideas for a hospital emergency department
  - A simulation-integer-linear-programming-based tool for scheduling emergency room staff
- **Additional Applications**
  - Managing workforce resource actions with multiple feedback control
  - Analyzing the impact of hole-size on putting in Golf
  - Real – time delay estimation in call centers

1.6 SYSTEMS AND SYSTEM ENVIRONMENT

A ***system*** is defined as a group of objects that are joined together in some regular interaction or interdependence toward the accomplishment of some purpose. For example, a production system producing automobiles is a collection of machine components and the workers operate jointly to assemble a vehicle.

A system is affected by external changes. Such changes are said to occur in ***system environment***. In modeling the systems, one should decide the ***boundary*** between the system and its environment. For example, the reasons for delay in components arrival may be considered as system environment for a production system.

1.7 COMPONENTS OF A SYSTEM

To understand and analyze the system, following terms should be known:

- **Entity:** It is an object of interest in the system
- **Attribute:** A property of an entity
- **Activity:** Represents a time period of specified length
- **State:** The state of a system is a collection of variables necessary to describe the system at any time, with respect to the objectives of the study.
- **Event:** An instantaneous occurrence that might change the state of the system
- **Endogenous:** Describes activities and events occurring within a system
- **Exogenous:** describes activities and events occurring in the environment that affects the system.

Examples for these components for some of the systems are given in Table 1.1.

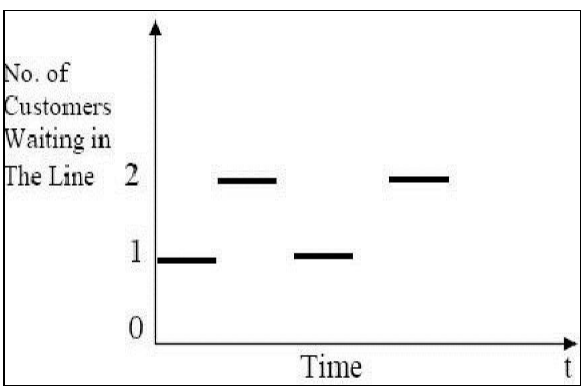
Table 1.1 Examples of Systems and their components

System	Entities	Attributes	Activities	Events	State Variables
Banking	Customers	A/c balance	Making deposits	Arrival, Departure	Number of busy tellers, number of customers waiting
Rapid Rail	Riders	Origin, Destination	Traveling	Arrival at station, arrival at destination	Number of riders waiting at each station, number of riders in transit
Production	Machines	Speed, capacity, breakdown rate	Welding, stamping	Breakdown	Status of machines like busy, idle, down
Communi-cations	Messages	Length, Destination	Transmitting	Arrival at destination	Number of messages waiting to be transmitted
Inventory	Warehouse	Capacity	Withdrawing	Demand	Levels of inventory, backlogged demands

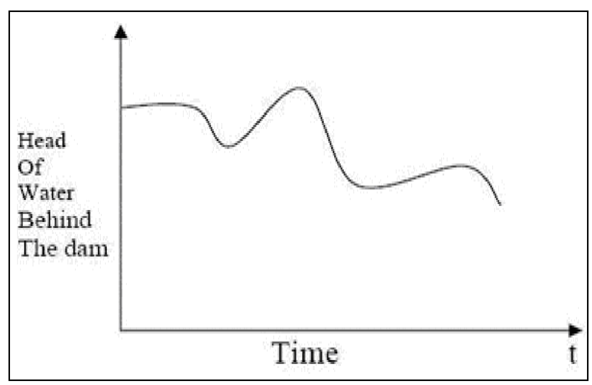
1.8 DISCRETE AND CONTINUOUS SYSTEM

A system can be categorized as discrete or continuous as explained below:

- **Discrete Systems:** A system in which state variables chance only at a discrete set of points in time is called as discrete system. For example, the number of customers in a bank varies only when either a customer goes out or comes in. It is shown in Figure 1.1(a).
- **Continuous Systems:** Here, the state variables change continuously over the time. For example, the water level in a dam may vary due to inflow (like heavy rain) or outflow(like opening gates of the dam, water evaporation). Refer Figure 1.1(b)



(a)



(b)

Figure 1.1 (a) Discrete – system state variable (b) Continuous – System state variable

1.9 MODEL OF A SYSTEM

To understand the relationships between the system components and to predict its operational behavior, it is necessary to study the system carefully. Sometimes, it is possible to experiment with the system itself. But, in many cases, the experimentation with the actual system may not be feasible. Hence, a model or prototype of the system is required.

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A ***model*** is defined as a representation of a system for the purpose of studying that system. For most studies, only few parameters that may affect the problem are enough in the model. That is, models include only relevant entities, attributes and activities of the actual system. At the same time, the model should be detailed enough to deduce valid conclusions about the real system. Different models of the same system may be required for a change in investigation.

1.10 TYPES OF MODELS

A model can be classified in a different ways on different grounds as given below:

- **Mathematical v/s Physical Model:** A mathematical model is represented using symbols and equations. A simulation model is a particular type of mathematical model of a system. A physical model is a larger/smaller version of an object such as enlargement of an atom or a scaled-down version of the solar system.
- **Static v/s Dynamic Model:** Static simulation model (also known as Monte Carlo simulation model) represents a system at a particular point in time. Dynamic models represent systems over a period of time. Simulation of a bank during working hours of one day is an example for dynamic simulation model.
- **Deterministic v/s Stochastic Model:** A simulation model that does not contain random variables is deterministic model. They normally have known set of inputs and will results in unique set of outputs. Example: if all the patients arrive at respective scheduled time, then it is a deterministic model. A stochastic (means, probabilistic) model contains random variables as inputs and hence results into random outputs. As the outputs are random, they are considered as estimates of the true characteristics of a model. Example: simulation of a bank involve random inter-arrival times and random service times. Thus, in a stochastic model of the banking, the average number of customers and average waiting time of each customer must be treated as estimates of the actual system.
- **Discrete v/c Continuous Model:** These two models are briefed in Section 1.8. Generally, discrete model is used to model discrete systems and so is the case with continuous model. But, they can be used even interchangeably and also they can be mixed as well.

1.11 DISCRETE – EVENT SYSTEM SIMULATION

Discrete-event system simulation is the modeling of systems in which the state variable changes only at a discrete set of points in time. In this method, the simulation models are analyzed by numerical methods rather than analytical methods. Here, an artificial history of the system is generated from the assumptions, observations are collected for analysis and system performance is estimated.

1.12 STEPS IN A SIMULATION STUDY

Various steps to be followed in building a simulation model is explained hereunder (Figure 1.2).

1. **Problem Formulation:** Every study should begin with a problem statement. The problem statement must clearly be understood by both the policy maker and the

analyst. Though, both of them have agreed upon the problem statement, there is a possibility of reformulation of problem statement during the course of simulation.

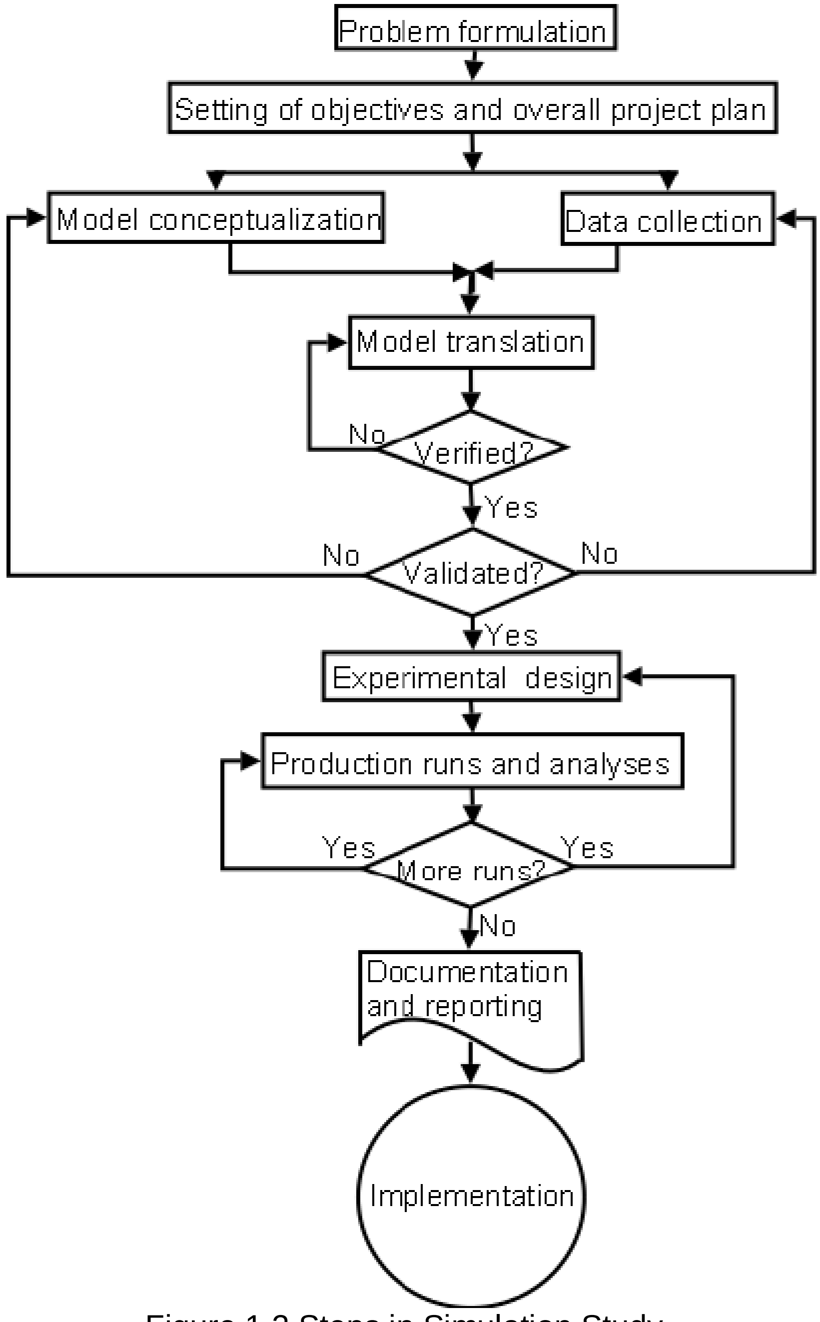

Figure 1.2 Steps in Simulation Study

2. **Setting of Objectives and overall Project Plan:** Objectives would be – What questions to be answered by a simulation model? At this stage, one should also consider whether the simulation is the appropriate tool for solving the problem for a given set of objectives or not. This step also should include the plans for the study like number of people involved, cost of the study, time required, expected result etc.

3. **Model Conceptualization:** One should start with building a simple model and then enhancing it with a greater complexity. It is better to involve the user of the model while building a model. This will help to improve the quality of the model and increase the confidence of the user while using it.

4. **Data Collection:** Building a model and the collection of input data are intervened. That is, as the complexity of the model changes, the required data elements also can change. Hence, data collections may take huge amount of time of model building.

5. **Model Translation:** The models of most of the real world systems require information storage and computation. Hence, the model must be entered into a computer-recognizable format.

6. **Verified? :** Verification pertains to the computer program that has been prepared for the simulation model. One has to verify whether the computer program is working properly. It involves the common sense for getting the answer.

7. **Validated? :** The model is compared iteratively with the actual system behavior and hence validated. If there are discrepancies, model is improved. This procedure is repeated till the accuracy of the model is acceptable.

8. **Experimental Design:** The alternative models have to be designed and which model to simulate has to be determined. For each system design model that has been simulated, few points like time required for initialization, time required for running the simulation etc must be noted. Based on the comparison, one has to choose the proper model.

9. **Production runs and Analysis:** Production runs and their subsequent analysis are used to estimate measures of performance for the system designs that are being simulated.

10. **More Runs? :** After analyzing the completed runs, the analyst must determine whether additional runs are needed or not.

11. **Documentation and Reporting:** There are two types of documentations:
    1. Program documentation: Can be used again by the same or different analysts to understand how the program operates. Further modification will be easier. Model users can change the input parameters for better performance.
    2. Progress documentation: Gives the history of a simulation project. The result of all analysis should be reported clearly and concisely in a final report. This enables to review the final formulation and alternatives, results of the experiments and the recommended solution to the problem. The final report provides a vehicle of certification.

12. **Implementation:** The success of the implementation depends on the previous steps. If the model user has been involved in model building process and if he/she understood the nature of the model and its outputs, then implementation will be enhanced. The simulation-model building process shown in Figure 1.2 can be divided into four phases:
    1. **First phase** consists of Step 1 and Step 2 and is a period of discovery or orientation. The initial statement of the problem is usually fuzzy, the objectives may need to be reset, and original project plan may need to be fine-tuned. These recalibrations and clarifications could occur in this phase.
    2. **Second phase** consists Step 3 to Step 7. A continuing interplay is required among these steps.
    3. **Third phase** involves running the model and includes Step 8 to Step 10. This phase has plan for experimentation and statistical analysis.
    4. **Fourth phase** is constituted by Step 11 and Step 12. The successful implementation depends on continual involvement of the model user and on the successful completion of every step in the process.