Chapter 1

CONCEPTS OF SIMULATION

1.1 Introduction

Simulation is the representation of a real life system by another system, which depicts the important characteristics of the real system and allows experimentation on it. In other words, simulation is an imitation of the reality. Though the formal use of the simulation technique is not very old, simulation has long been used by the researchers, analysts, designers and other professionals in the physical and non-physical experimentations and investigations. In our day-to-day life, we use simulation, even without realizing it. Globe imitates some important geographical characteristics of the earth. Scale models of various machines and plants are used in laboratories to study their performance characteristics. Simple models of machines are used to simulate the plant layouts. A model aeroplane suspended in a wind tunnel simulates a real sized plane moving through the atmosphere, and is used to study the aerodynamic characteristics. A children cycling park, with various crossings and signals is a simulated model of the city traffic system. A planetarium represents a beautiful simulation of the planetary system. Environments in a geological park and in a museum of natural history are other examples of simulation.

In each of these examples, the real system has been substituted by physical model, which is not possible in case of complex and intricate problems of managerial decision making. The inventory management system, complicated waiting lines, manufacturing system etc., cannot be imitated physically. In such cases, a series of mathematical and logical statements are used to represent the system. Simulation of this type involves a huge amount of computations, which are possible only with the help of a powerful computing system, and hence the name computer simulation or system simulation.

It can be said that system simulation is mimicking of the operation of a real system, such as the day-to-day operation of a bank, or the running of an assembly or production line in a factory, or assignment of salesman to different sales areas. A simulation is the execution of a computer model of the system that is a computer program, to get information about the system. It is like conducting an experiment on the system, and as compared to purely theoretical analysis, simulation is much flexible and convenient. The readily available simulation softwares has made it possible for managers who are not computer programmers or expert analysts, to model and analyze the operation of real systems. Before going into further details, it will be appropriate to discuss the concept of system.

1.2 The System

The term 'System' is a word of everyday use. It is used in a large variety of situations and in such a variety of ways, that it has become very difficult to give a definition sufficiently broad to cover the variety of uses, and concise enough to serve the purpose. There are many definitions found in literature, but none can universally be applied. Klir* gives a collection of 24 definitions and one such definition is, "A system is a collection of components wherein individual components are constrained by connecting interrelationships such that the system as a whole fulfills some specific functions in response to varying demands".

* Klir, George J., *An Approach to General Systems Theory*, New York : Van Nostrand Reinhold Co., 1969

In simple, the system has also been defined as "an aggregation or assemblage of objects joined in some regular interaction or interdependency."

(Gorden Geoffrey, *System Simulation*, Prentice Hall of India, New Delhi, 1980)

These definitions seem to be more relevant to the physical and static systems comprising of components or objects, connected by some physical laws. A more comprehensive definition must include the dynamic effects, where the interactions cause changes over time.

A simple example of system can be taken of an engine governor, which is required to keep the speed constant within limits, at varying loads on the engine (Fig. 1.1). As the load is changed, speed changes, governor balls lift or lower the sleeve, which controls the fuel supply, and in turn the speed. It is an automatic control system.

A manufacturing system comprises of a number of departments such as production control department, purchase department, fabrication, assembly, finishing, packaging, inspection and quality control, shipping and personnel department etc. All of these departments are interlinked to maintain

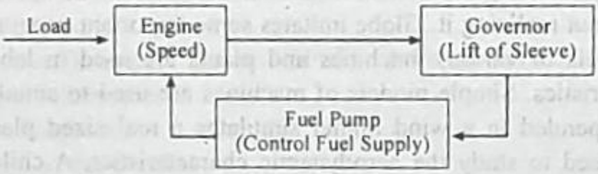

Fig. 1.1

the proper flow of the materials and information. These components of the manufacturing system are individually very complicated and the system as a whole becomes very complex.

In case of a governor system, the components of the system, the engine, governor, fuel pump etc., are all physical. Their interrelationships are based on well-known physical laws. Such systems are called physical systems.

The manufacturing system, on the other hand comprises of a large number of departments, with man made interrelationships, which cannot be represented by physical objects. Such systems are classified as non-physical systems. Management systems, social system, education system, political system etc. are all non-physical systems.

The behavior of one component of a system affects the performance of other components due to interconnections and hence, when a system is identified it has to be described and studied as a whole. This methodology of tackling the system is called *systems approach*. We may also call it the scientific approach. The term *system engineering* has been used for engineering employing systems approach.

The performance of a system is often affected by the activities occurring outside the system. The availability of raw materials, power supply, demand of goods etc., are activities, which will affect the performance of the manufacturing system. Similarly some activities may also produce changes that may not affect the system at all. All these changes, which occur outside the system, constitute the system environment. Thus, while describing a system, it is an important step to draw a boundary between the system and its environment. How and where the boundary is to be drawn depends upon the purpose of modeling the system. For example, if in a manufacturing system the effect of a particular work place lay out is to be studied, then activities like inspection, purchasing, packaging, inprocess inventory level etc., are all external to the system. On the other hand if the idle time of bank teller is to be studied, the arrival of customers is an activity internal to the system. Activities, which occur within the system, are called *endogenous activities*, while those occurring in environment are called *exogenous activities*. A system for which there is no exogenous activities, that is the system that is not affected by its environment, is said to be *closed system*, while a system, which is affected by the activities occurring outside its boundary, is called an *open system*.

In each system, there are some distinct components, which are of interest in a particular investigation. While the term *entity* is used to denote the component of interest, the property of interest of the entity is called its *attribute*. There can be many attributes to an entity. In a traffic system vehicles say buses, trucks and cars may be the entities while speed, distance moved, noise produced, exhaust emission, number of accidents etc., may be the attributes of each entity. Which of these are of interest will depend upon the purpose of investigation.

The process, which causes change in any attribute of an entity of a system, is called an *activity*. In case of traffic system, driving may be an activity. The term, state of the system at a possible time, is the description of all entities, attributes and activities, as they exist at that particular point in time.

Some other terms, which are frequently encountered while dealing with a system, are given below.

Queue: It is a situation, where entities wait for some thing to happen. It may be physical queue of people, or of objects, or a list of tasks to be performed.

Creating: Creating is causing an arrival of a new entity to the system at some point in time.

Scheduling: Scheduling is the process of assigning events to the existing entities, like the service begin and service and times.

Random variable: It is a variable with uncertain magnitude, *i.e.*, whose quantitative value changes at random. The inter arrival times of vehicles arriving at a petrol pump, or the life of electric bulbs are random variables.

Random variate: Random variate is a variable generated by using random numbers along with its probability density function.

Distribution: It is a mathematical law which governs and defines probabilistic features of the random variables. It is also called probability density function.

Let us take the example of a petrol pump, where vehicles arrive at random for getting petrol or diesel. In this case,

Entities are vehicles which will comprise of various types of four, three and two wheelers.

Events are arrival of vehicles, service beginning, service ending, departure of vehicles.

States: or state variables are the number of vehicles in the system at a particular time, number of vehicles waiting, number of workers busy, etc.

Attributes: Type of vehicle-four wheeler, two wheeler, petrol or diesel, size of fuel tank, filling rate of machine, etc.

Queue: Vehicles waiting in front of the pump.

Random variables: Inter arrival times of vehicles, service times and billing times, etc.

Distribution: The distribution may be one of the many statistical probability density functions. It is generally assumed to be exponential in case of queuing systems.

Table 1.1 lists the examples of entities, attributes, activities, events and state variables for a few systems. This table does not show a complete list of all entities, attributes, activities, events or states of the system, as the complete list can be made only when the system is properly defined.

Table 1.1

System	*Entities*	*Attributes*	*Activities*	*Events*	*State variables*
Banking	Customers	Balance, Credit status	Making deposits, withdrawls	Arrivals, departures	Number of customers waiting, number of busy tellers
Traffic control lights	Vehicles	Distance, speed, type of vehicle	Driving	Stopping, starting	Status of traffic signals, number waiting, time to green
Production	Machines, Work pieces	Processing rates, breakdown times	Machining, welding, sampling, moving of work pieces	Work arrives at machine, processing starts, ends	Machine busy, Work piece waiting, machine down
Super market	Customers, trolleys, baskets	Shopping list	Collecting items, checking out	Arrival in store, collect basket, end shopping	Availability of stock, variety, number of shoppers waiting for check out
Communication	Messages	Length, priority, destination	Transmitting	Sending time, arrival at destination	Massages waiting to be transmitted

1.3 Continuous and Discrete Systems

From the viewpoint of simulation, the systems are usually classified into two categories,

- Continuous systems
- Discrete systems

System in which the state of the system changes continuously with time are called continuous systems while the systems in which the state changes abruptly at discrete points in time are called discrete systems. The pure pursuit problem represents a continuous system since the state variables, the locations of target and pursuer, varies continuously with time. The inventory systems discussed in Chapter 7 and the queuing systems discussed in Chapter 6 are examples of discrete systems. In case of inventory system, the demand of items as well as the replenishment of the stock occur at discrete points in time and also in discrete numbers. Similarly in case of queuing systems the customers arrive and leave the system at discrete points in time. Generally the systems in which the relationships can be expressed by mathematical expressions as in engineering and physical sciences, turn out to be continuous systems, while the systems encountered in operations research and management sciences are generally discrete systems. In continuous systems, the variables are by and large deterministic while discrete systems generally deal with stochastic situations. Few systems are wholly continuous or discrete. In reservoir problem sudden heavy rains or sudden heavy release may result into sudden changes in the state of the system and may call for discrete treatment. In a factory system though the start and finish of a machine are discrete points but the machining process is continuous. Thus, no specific rules can be laid for the development of simulation models. However, effort should be made to reach a judicious balance between the simplicity of the model and the desired level of detail and accuracy of results.

1.4 Types of Models

The models used for the analysis of various types of systems have been classified in a number of ways, as shown in Fig. 1.2.

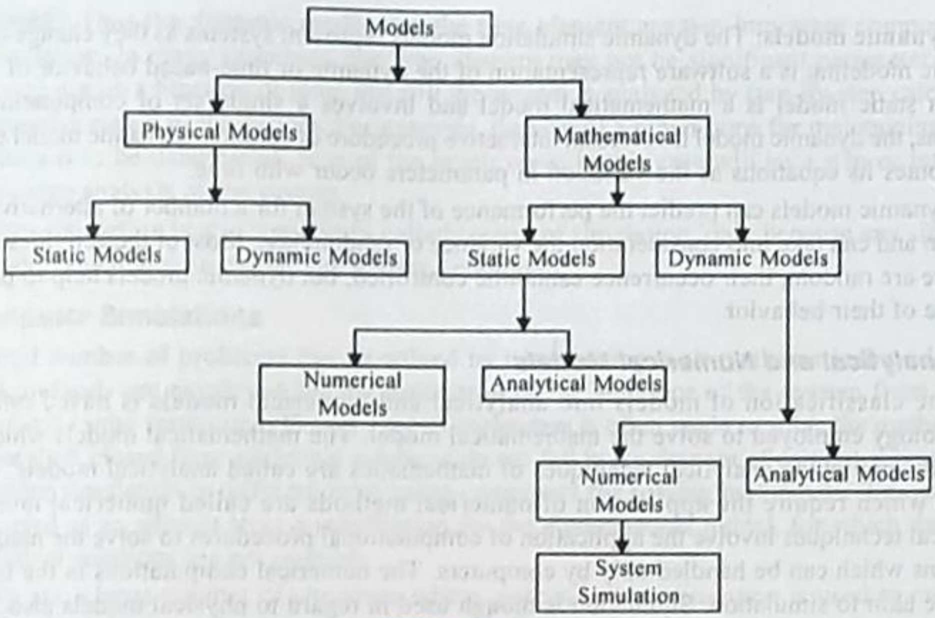

Fig. 1.2 Types of models

1.4.1 *Physical and Mathematical Models*

The first major classification of models is into physical models and mathematical models.

Physical models: In physical models, physical objects are substituted for real things. Physical models are based on some analogy between the model and simulated system. These models may comprise of only physical objects without any dynamic interaction between them, or physical objects where there is dynamic interaction between the components or the attributes of the system. Representation of mechanical systems by electrical systems, of hydraulic system by electrical systems, and vice-versa are examples of physical models. Here, the mechanical attributes like pressure, speed and load etc. are represented by properties like voltage, current and resistance etc. It can be said that in physical models, a physical representation is prepared for studying the system.

Mathematical models: The mathematical models comprise of symbolic notations and mathematical equations to represent the system. The system attributes are represented by the variables like the controlled and dependent variables, while the activities or the interaction between the variables are represented by mathematical functions. The mathematical models can be static as well as dynamic and further analytical, numerical or simulation models, depending upon the techniques employed to find its solution.

1.4.2 *Static and Dynamic Models*

Static models: A static model represents a system, which does not change with time or represents the system at a particular point in time. Static models describe a system mathematically, in terms of equations, where the potential effect of each alternative is ascertained by a single computation of the equation. The variables used in the computations are averages. The performance of the system is determined by summing the individual effects.

Since the static models ignore the time dependent variables, these cannot be used to determine the influence of changes which occur due to the variations in the parameters of the system. The static models, do not take into consideration the synergy of the components of the system, where the action of separate elements can have a different effect on the modeled system then the sum of their individual effect could indicate.

Dynamic models: The dynamic simulation models represent systems as they change over time. Dynamic modeling is a software representation of the dynamic or time-based behavior of a system. While a static model is a mathematical model and involves a single set of computations of the equations, the dynamic model involves an interactive procedure of solution. Dynamic model constantly re-computes its equations as the variation in parameters occur with time.

Dynamic models can predict the performance of the system for a number of alternative courses of action and can take into consideration the variance or randomness. Most of the activities occurring in nature are random, their occurrence cannot be controlled, but dynamic models help to predict the outcome of their behavior.

1.4.3 *Analytical and Numerical Models*

The classification of models into analytical and numerical models is based only on the methodology employed to solve the mathematical model. The mathematical models which can be solved by employing analytical techniques of mathematics are called analytical models, while the models which require the application of numerical methods are called numerical models. The numerical techniques involve the application of computational procedures to solve the mathematical equations which can be handled only by computers. The numerical computations in the interactive form are akin to simulation. Simulation is though used in regard to physical models also, but most of the applications have been found in mathematical modeling and further for modeling the dynamic and stochastic behavior of the systems.

1.4.4 *Deterministic and Stochastic Models*

Deterministic models: The deterministic models have a known set of inputs, which result into a unique set of outputs. In case of pure pursuit problem discussed in section 3-2, the initial position of the target and pursuer, their speeds and the path of flight are known and can be expressed by mathematical equations. For a given set of inputs there can be only one output. This model is deterministic. Occurrence of events is certain and not dependent on chance.

Stochastic models: In stochastic simulation models, there are one or more random input variables, which lead to random outputs. The outputs in such a case are only estimates of true characteristics of the system. The waiting line system, where the arrival of customers is random is a stochastic system. The working of a production line, where the operation times at different work station are random is a stochastic process. The random variables in a stochastic system may be represented by a continuous probability function or these may be totally discrete. Depending upon the distribution of random variables, stochastic models can be further divided into continuous models and discrete models. Because of the randomness of the variables, the results of stochastic simulations are always approximate. To obtain reliable results, a stochastic simulation model has to be run for a sufficiently long duration

1.5 System Simulation

In the introduction to the subject, a variety of examples have been given to explain the concept of simulation. In that context, forming of a physical model and experimenting on it is simulation. Developing a mathematical model and deriving information by analytical means is simulation. Where analytical methods are not applicable numerical methods or specific algorithms are applied to analyze the mathematical models, which again is simulation. These models, physical as well as mathematical can be of a variety of types. Thus the term simulation described as a procedure of establishing a model and deriving solution from it covers the whole gamut of physical, analogue, analytical and numerical investigations. To distinguish this interpretation of simulation from more general use of the technique the term system simulation is used. Geoffrey Gorden has defined system simulation as "the technique of solving problems by observation of the performance, over time, of a dynamic model of the system." Thus the dynamic model and the time element are two important components of system simulation. In many situations, the time element may not be significant parameter. System behavior may not be a function of time, but still the system is analyzed by step-by-step calculations of the successive stages of the system. For example, the size of a repair crew for maintaining a fixed fleet of buses is to be determined. Size of the repair crew, in this case will be a step or interval in the step-by-step analysis of the system.

System simulation is also sometimes called computer simulation, only because any simulation worth the name can only be carried out within a computer.

1.6 Computer Simulations

A good number of problems can be solved by constructing their mathematical models. The analytical methods are employed for the prediction of the behavior of the system from a set of parameters and initial conditions. Though, use of computers is often made to solve the mathematical models, but their closed form analytical solutions do not fall in the domain of computer simulations. The computer simulation is different from using computers for solving mathematical models. It is generally used as an adjunct to or a substitution for the mathematical model, for which the closed form analytical solutions are not possible.

There are a large number of situations where *discrete event simulation* is used to model the system of interest, like in manufacturing, commerce, defence, health etc. The complexities of such situations cannot be handled by any mathematical model. The IF and WHAT type models has to be constructed to study the influence of selected parameters on the performance of the system, *Theory of constraints*, *bottlenecks* and *management consulting* are other identical situations, which are too complex to be handled without the computer simulation.

Several software packages exist for running computer simulations or computer-based simulations. Computer simulations are also referred to as *human out of loop* simulations. These have become an important tool of modeling many natural systems in economics and social sciences as well as in engineering.

An interesting application of computer simulation is to simulate the computers using computers. The related software is called *architecture computer simulator*, which can be further divided into *instruction set simulator or full system simulator*.

The term "*synthetic environment*" is also being used these days for simulations of many kinds. This term has been adapted to broaden the definition of simulations to encompass virtuality and computer-based representation.

1.7 Physical and Interactive Simulation

The physical simulation has already been discussed in sections 1.4.1, where some examples of physical models, were also given. It can be said that ***physical simulation*** refers to simulations in which physical objects are substituted for real things. These physical objects are often chosen because of their size, cost and convenience of use. These physical simulation models are always cheap to construct and safe to use. The model of an aeroplane wing placed in wind tunnel is a physical model.

Interactive simulations: As the name suggests interactive simulation is a special kind of physical simulation in which the human operator interacts with the physical model. The flight simulator and an automobile driving simulator are examples of interactive simulations. The interactive physical simulation is also referred to as a *human in the loop simulation*. Human is an essential part of the interactive simulation.

1.8 Real-Time Simulation

In many situations, the simulation of the complete system is either highly complicated or is not desirable form the application point of view. An actual physical part of the system is integrated with a computer, which simulates the parts of the system that do not exist or that cannot conveniently be used in the experiment. Such systems usually involve interaction with a human being thereby avoiding the need to design and validate a model of human behavior. The aircraft cockpit simulator for the training of pilots and the simulated zero gravity chambers for the training of astronauts are examples of real-time simulators. These systems are called real time because the time taken by the experiment will be real that is the same as in case of a completely physical system. The real time simulation requires computers that can operate in real time; this means that they must be able to respond immediately to signals sent from physical devices, and send out signals at specific points in time.

1.9 Comparison of Simulation and Analytical Methods

In contrast to analytical models, the simulations are "run" rather than solved. Running a simulation is like conducting an experiment and an experiment always gives specific solutions depending upon the input conditions and characteristics of the system, while the analytical methods give general solutions. For example in an optimization problem, the mathematical model will give optimum value in a single solution and in case of simulation model a number of simulations will have to be executed, each resulting in a different value, one of which will approximate the optimum value.

The results obtained by simulation are approximate while the results obtained by analytical methods are exact. To increase the reliability of simulation results, simulation has to be run for longer periods. However in case of complex situation, mathematical modeling becomes difficult and many assumptions and simplifications have to be made for constructing the model. In such cases, the analytical model may give highly approximate or unrealistic results. It is a question of judgement up to what level the system has to be approximated or abstracted to fit a mathematical model.

The accuracy of simulation results depends upon the level of details at which the mode has been developed. More detailed is the model, more complex is its construction. More detailed simulation mode requires greater time and effort to construct the model and its execution takes longer run time. Thus a compromise has to be made for the level of detail, to obtain reasonably realistic results.

The mathematical models can handle only a limited range of problems, while simulation can handle all sorts of problems. It is said that when every method fails, simulation can be employed to solve the problem.

1.10 When to Use Simulation?

Over the years, tremendous developments have taken place in computing capabilities and in special purpose simulation languages, and in simulation methodologies. The use of simulation technique has also become widespread. The situation under which simulation should be used, have been discussed by many authors, and it is essential to understand the purposes and situation, where this technique should be employed. Following are some of the purposes for which simulation may be used.

1. Simulation is very useful for experiments with the internal interactions of a complex system, or of a subsystem within a complex system.
2. Simulation can be employed to experiment with new designs and policies, before implementing them.
3. Simulation can be used to verify the results obtained by analytical methods and to reinforce the analytical techniques.
4. Simulation is very useful in determining the influence of changes in input variables on the output of the system.
5. Simulation helps in suggesting modifications in the system under investigation for its optimal performance.

1.11 Steps in Simulation Study

Like any other problem solving approach, simulation is also carried efficiently, if it is done in a predetermined orderly manner. The total procedure has been divided into different number of steps by different authors. In general a simulation study can be divided into following prominent steps:

- Problem formulation
- Model construction
- Data collection
- Model programming
- Validation
- Design of experiment
- Simulation run and analysis
- Documentation
- Implementation

1.11.1 *Problem Formulation*

The clear and unambiguous description of the problem, definition of the objectives of the study, identification of alternatives to be considered and methodology for evaluating the effectiveness of these alternatives needs to be stated at the beginning of any study. If the statement of the problem is provided by the policy makers, the analyst must ensure that the problem being described is clearly understood. Alternatively, if the problem statement is being formulated by the analyst, the policy makers should be able to understand it and accept it. At this stage, it should also be ascertained, whether the simulation technique is the appropriate tool for solving the problem. The overall plan should include a statement of the alternative systems to be considered, the measures of performance to be used, the methodologies of analysis to be used, and the anticipated result of the study.

1.11.2 *Model Construction*

The model building is much of an art than science. There are no standard rules for building a successful and appropriate model for all types of situations. There are only certain guidelines, which can be followed. The art of modeling is enhanced by the ability to abstract the essential features of the system, to select and modify the basic assumptions and simplifications that characterize the system, and then improve and elaborate the model. To start with a simple model is constructed, which is modified step-by-step, every time enriching and elaborating its characteristics, to achieve an appropriate model, which meets the desired objectives. In some situations, building block method is employed, where the blocks of components of system are built and validated. These blocks are then combined to obtain model for the complete system.

1.11.3 *Data Collection*

The availability of input data about the system is essential for the construction of its model. The kind of data to be collected depends upon the objectives of the study, the required data may be available as past history, or may have to be collected. The construction of the simulation model and the collection of data have a constant interplay, and the type and amount of data required may change as the model develops. The data is required not only as an input to the model, but also some data is used to validate the simulation model. Since data collection generally takes longer time, it should be started as early as possible.

1.11.4 *Model Programming*

Any simulation model worth the name requires enormous amount of computations and information storage, which is possible only with the use of high-speed computers. The translation of the model into a computer recognizable format is termed as programming. Many general and special purpose simulation languages are available to write simulation programs. Many special purpose and problem specific simulation softwares have been developed which can be used for simulation modeling. It is for the modeler to decide, whether a simulation language is to be used or special purpose software is to be used. If the situation under study is amenable to an available special purpose software, the model development time and effort is considerably reduced. On the other hand, simulation languages are usually more powerful and more flexible than the special purpose software packages. The general programming languages like BASIC, FORTRAN, C, C++ have also been extensively used for writing the simulation programs.

1.11.5 *Validation*

It is essential to ensure that the model is an accurate representation of the system, which has been modeled. That the computer program performs properly and the results obtained are identical to the ones from the real system. Validation involves both the validation of the logic and accuracy of programming. This requires step-by-step modification of the model. It is rarely possible to develop a reasonably large simulation model in its entirety in first step. Good deal of debugging is required. The validation is thus an iterative process of comparing the model to actual system behavior, identifying the discrepancies, applying corrections and again comparing the performance. This process continues till a model of desired accuracy is obtained. The data collected from the actual system is of great help in validation of the model.

1.11.6 *Design of Experiment*

The simulation is basically experimentation on the model of the system under investigation. Simulation experiment in most of the situations involves stochastic variables, which result into stochastic results. The average values of result obtained may not be of desired reliability. To make the results meaningful, it is essential that simulation experiment be designed in such a way that the results obtained are within some specified tolerance limits and at a reasonable level of confidence. Decisions regarding the length of simulation run, initial conditions, removal of initial bias, number of replications of each run; use of variance reduction techniques etc. has to be made.

1.11.7 *Simulation Run and Analysis*

The simulation program is run as per the simulation design; the results are obtained and analyzed, to estimate the measures of performance of the system. Based on the results, a decision is made, whether or not any modification in the design of simulation experiment is needed. This step is a sort of validation of the simulation design. It may reveal that more runs or more replications are required.

1.11.8 *Documentation*

Documentation of a simulation program is necessary as the program can be used by the same or different analyst in future. The program can be used with modifications for some other identical situation, which can be facilitated if the program is adequately documented. Documentation of the simulation model, allows the user to change parameters of the model at will to investigate the influence on outputs, to find optimal combinations. The program should be so documented, that a new user can easily understand it.

1.11.9 *Implementation*

There will not be any problems in the implementation of the simulation program, if the user is fully conversant with the model, and understands the nature of its inputs and outputs and underlying assumptions. Thus, it is important that the model user is involved in the development of the simulation model from the very first step.

1.12 Phases of a Simulation Study

The process of simulation model development has been detailed under nine steps in the previous section. Some authors divide this process into following four phases:

Phase 1: Problem formulation: This includes problem formulation step.

Phase 2: Model building: This includes model construction, data collection, programming, and validation of the model.

Phase 3: Running the model: This includes experimental design, simulation runs and analysis of results.

Phase 4: Implementation: This includes documentation and implementation.

1.13 Advantages of Simulation

The use of the simulation technique is widespread, and it is gaining popularity day-by-day. There are many advantages of this technique over the other techniques. Some of these are given below.

1. Simulation helps to learn about a real system, without having the system at all. For example, the wind tunnel testing of the model of an aeroplane does not require a full sized plane.
2. Many managerial decision making problems are too complex to be solved by mathematical programming.
3. In many situations, experimenting with an actual system may not be possible at all. For example, it is not possible to conduct experiment, to study the behavior of a man on the surface of moon. In some other situations, even if experimentation is possible, it may be too costly and risky.
4. In the real system, the changes we want to study may take place too slowly or too fast to be observed conveniently. Computer simulation can compress the performance of a system over years into a few minutes of computer running time. Conversely, in systems like nuclear reactors where millions of events take place per second, simulation can expand the time to required level.
5. Through simulation, management can foresee the difficulties and bottlenecks, which may come up due to the introduction of new machines, equipments and processes. It thus eliminates the need of costly trial and error method of trying out the new concepts.
6. Simulation being relatively free from mathematics can easily be understood by the operating personnel and non-technical managers. This helps in getting the proposed plans accepted and implemented.
7. Simulation models are comparatively flexible and can be modified to accommodate the changing environment to the real situation.
8. Simulation technique is easier to use than the mathematical models, and can be used for a wide range of situations.
9. Extensive computer software packages are available, making it very convenient to use fairly sophisticated simulation models.
10. Simulation is a very good tool of training and has advantageously been used for training the operating and managerial staff in the operation of complex systems. Space engineers simulate space flights in laboratories to train the future astronauts for working in weightless environments. Airline pilots are given extensive training on flight simulators, before they are allowed to handle real aeroplanes.

1.14 Limitations of the Simulation Technique

In spite of all the advantages claimed by the simulation technique, many operations research analysts consider it a method of last resort, and use it only when all other techniques fail. If a particular type of problem can be shown to be well represented by a mathematical model, the analytical approach is considered to be more economical, accurate and reliable. On the other hand, in very large and complex problems, simulation may suffer from the same deficiencies as other mathematical techniques. In brief, simulation technique suffers from following limitations.

1. Simulation does not produce optimum results. When the model deals with uncertainties, the results of simulation are only reliable estimates subject to statistical errors.
2. Quantification of the variables is another difficulty. In a number of situations, it is not possible to quantify all the variables that affect the behavior of the system.
3. In very large and complex problems, the large number of variables, and the inter-relationships between them make the problem very unwieldy.
4. Simulation is by no means a cheap method of analysis. Even small simulations take considerable computer time. In a number of situations, simulation is comparatively costlier and time consuming.
5. Other important limitation stem from too much tendency to rely on the simulation models. This results in applications of the technique to some simple situations, which can more appropriately be handled by other techniques of mathematical programming.

1.15 Areas of Applications

System simulation is a technique, which finds applications in almost each and every field. Some of the areas in which it can be successfully employed are listed below:

Manufacturing: Design analysis and optimization of production system, materials management, capacity planning, layout planning and performance evaluation, evaluation of process quality.

Business: Market analysis, prediction of consumer behavior, optimization of marketing strategy and logistics, comparative evaluation of marketing campaigns.

Military: Testing of alternative combat strategies, air operations, sea operations, simulated war exercises, practicing ordinance effectiveness, inventory management.

Healthcare applications: Such as planning of health services, expected patient density, facilities requirement, hospital staffing, estimating the effectiveness of a health care program.

Communication applications: Such as network design and optimization, evaluating network reliability, manpower planning, sizing of message buffers.

Computer applications: Such as designing hardware configurations and operating system protocols, sharing and networking.

Economic applications: Such as portfolio management, forecasting impact of Govt. Policies and international market fluctuations on the economy, budgeting and forecasting market fluctuations.

Transportation applications: Design and testing of alternative transportation policies, transportation networks — roads, railways, airways etc., evaluation of timetables, traffic planning.

Environmental applications: Solid waste management, performance evaluation of environmental programs, evaluation of pollution control systems.

Biological applications: Such as population genetics and spread of epidemics.

There is no end to the list of applications. There is no area, where the technique of system simulation cannot be applied. However, the analyst must look into the possible mathematical techniques, before deciding to use simulation. In many situations, the use of simulation is uneconomical. Also simulation produces only estimates of system performance, while mathematical analysis provides accurate answers. As the complexities of the problem increase, the scope of application of simulation increases.

1.16 Simulation — A Management Laboratory

The technique of system simulation is a very important tool of decision making. The managerial problems are generally too complex to be solved by the analytical techniques. Various techniques of operations research are applicable to only specific types of situations, and require many assumptions and simplifications to be made for fitting the problem into the model. Many of the events occurring in real systems are random with intricate interrelationships, with their solution beyond the scope of standard probability analysis. Under the circumstances, simulation is the only tool, which allows the management to test the various alternative strategies. Since, simulation is a sort of experimentation, and when used for analyzing managerial problems, it is rightly called the management laboratory. For training the business executives, simulations called management games are used in many universities and management institutes.

1.17 Simulation in Design

Computer simulation has been very effectively used by the managers, administrators, computer system users and designers, for achieving high performance at comparatively low costs. In addition to using simulation for better understanding the systems and for optimizing their performance and reliability, simulation is a very good tool for verifying the correctness of designs. Most of the digital integrated circuits manufactured today are first simulated and intensively tested and verified before they are manufactured. The design of most of the complicated systems like robots, transfer lines, flexible manufacturing systems and automated guided vehicles, are first tested on simulation models. Simulation along with animation helps to test the interactions and interferences of various components of a system. The manufacturing systems of various types varying from the flow line production systems to flexible manufacturing system are tested and validated on their simulation models. The analysis, design and balancing of assembly lines are carried out by simulation of the line. Complex civil engineering structures are first modeled and tested before their actual erection. Simulation helps to identify the errors in design and to do the necessary corrections and carry out the desired modifications. It is thus important that simulation is employed early in the design cycle because the cost of repairing mistakes increases dramatically when these are detected late in the design and manufacturing cycle. Simulation is also very helpful in evaluating the alternative designs, production schedules and processing plans.

1.18 Simulation in Computer Science

Simulation has played a very important role in the design, analysis and optimization of computing systems. In computer science, simulation has a very specialized meaning, where the term simulation refers to what happens when a digital computer executes a program. The whole operation of the digital computer is simulated and all information about the inputs, outputs, transaction of states taking place during execution becomes available to the programmer. This helps in designing the computer architecture and optimizing its operation. The programmer can easily test the alternatives in design at different speed with different input data. In theoretical computer science, 'simulation' represents relationships between state transitions in systems. Simulation helps in the study of operational semantics.

In computer architecture, a simulation is used to test a program that has to run on some inconvenient machine. Computer architecture simulators are available which are used to build the test computer architecture. The simulation is used to debug the computer program, which may be micro-program or commercial application.

Simulation is also used to analyze the *fault trees*. Simulation helps in better designing of circuits and optimizing their performance. All VLSI logic circuits are first simulated and tested then constructed.

1.19 Simulation in Training

Simulation has long been used in military training. Earlier it used to be physical simulation of war games on boards and now it has changed to computer war games. Simulation is a very useful technique of training in situations where it is either too dangerous or prohibitively expensive to impart training on real systems. Like the training of a pilot is never carried on a real aeroplane, it is first on a flight simulator where the pilot is thoroughly trained in using the various controls and instruments. There are situations where training on real equipments in real situations is not possible at all, like the training of astronauts to walk in space or on other planets and to work in zero gravity environment. Such trainings are given in simulated virtual environments, which are created in laboratories. These simulated equipments and environments are safe, economical and can be manipulated to suit the training requirements.

In army, any training that is not a real combat is defined to be a simulation. The same is true in other fields also. The purpose of the simulated training is to place people in situations, which replicate those they will experience in real situations, to test their reactive and decision making capabilities.

1.20 Classification of Training Simulations

The training simulations are classified into three broad categories; *Live*, *Virtual* and *Constructive*.

(*a*) *Live simulation*: In live simulation, real people use simulated equipment in real world. Real-time simulations are live simulations. Soldiers operate their real equipment in mock engagements. This simulated combat trains the troops to experience the rigors of living and working in the field.

(*b*) *Virtual simulation*: In virtual simulation, real people use simulated equipment in a simulated environment, also called virtual environment. The training of space astronauts is done on simulated equipment in virtual environment. In the military games, this is a modification of live simulation in the sense that real equipment is replaced by mock-ups and the field of battle is generated by a computer. In these simulators, soldiers practice at much lower operational cost and with greater freedom in taking risks. Since both the equipment and the battlefield are virtual, troops can practice actions which are too dangerous to attempt in live simulations. Live simulations on the other hand are limited to the terrain that is available at training sites only.

(*c*) *Constructive simulation*: In this type of simulation, simulated people use simulated equipment in a simulated environment. Constructive simulation is also called "war-gaming" It has extensively been used in military training. It is similar to table top war games in which simulated players command simulated armies of soldiers and equipments, that move around on a board.

While the 'Live' and 'Virtual' simulations are used to train individual to operate equipments, constructive simulation trains the commanders to face situations and make decisions under the stress of time and limited resources just as they will during the actual combat. Constructive simulation helps the commanders to test their strategies in situations where the enemy is highly trained, fully equipped, totally unpredictable and fully determined to win.

Simulation training has been employed in almost all the fields, where training on real system is not feasible like in medical science, space science, navy, air force and army and in managerial decision making, etc.

1.21 Simulation in Education

Tell me, I forget
Show me, I remember
Involve me, I understand

Simulation is an interactive teaching-learning technique which helps in better understanding of the learning materials. Educational simulations are creative units of instructions which incorporate traditionally taught material into a simulated environment. In addition to being a rich and flexible tool for teaching and learning, it provides instructors the evaluation procedures to assess how well they are educating their students.

The simulation has long been used in training, but now it is finding many important applications in education. Since training itself is a part of education, the education simulations are similar to training simulations. The educational technology researchers have shown that the video games are an efficient way of learning, and that these can be used very effectively in the teaching learning process, by preparing video games based on the school or college curriculum. The Animated Narrative Vignettes (ANV) are cartoon-like video narratives of hypothetical and realty-based stories. The simulated programmed learning helps the individual to learn at his own pace and convenience, and test his power of understanding and problem solving skills etc.

Simulation is finding extensive application in the science and engineering laboratories, where virtual experimental set up are being used for performing experiments. These are like training simulators. Animated learning materials are available for learning engineering drawing and other subjects.

Simulation has proved to be a tool of extreme importance in medical educations. A simulated patient or a model patient, saves putting the real human being into the hands of students and inexperienced doctors. Students can work without any hesitation and repeat the medical procedures any number of times on a simulated patient.

Since, simulation-based education cannot completely replace the traditional classroom education, a combination or blend of various education techniques, called "Blended Education" is being actually implemented. The idea behind blended learning is that the education designers, prepare a learning program, divide it into modules and determine the best medium to deliver those modules to learners. Thus it involves mixing various form of education like the classroom teaching, internet-based learning and simulated instructional modules delivered both on and off line.

The simulated education has some unique advantages.

- Simulation works very well over the internet, where instructional material can be delivered to a large population of learners spread over the globe.
- To an individual learner, simulated education allows to learn at his own pace and to repeat the process as many times as one requires for complete understanding.
- Simulated laboratories/equipments allow the learners to practice without any fear of damage to equipment. Especially in medical education, simulated patient provides an excellent apprehension free learning environment.

There are a good number of reasons why other forms of education must complement a simulation.

- Some concepts can be taught better by a teacher and understood better by discussion among fellow learners. This is especially true in case of many soft skills.
- Meeting face to face with the teacher can be highly motivating.
- In many situations, working on real equipments and in real environments gives better understanding of the system compared to simulated environment.

1.22 Medical Simulators

Medical simulators are increasingly being developed and used to teach therapeutic and diagnostic procedures as well as medical concepts to the medical students. The simulators have been deployed for educating and training in the procedures ranging from the basic as blood drawing to laparoscopic surgery and trauma cases. The medical simulators are extremely useful for development of new medical tools and equipments, new therapies and treatments and for making decision regarding medication and treatment. Biomedical engineering makes good use of simulators.

Simulators replace the real human subjects and take them out of the hands of the inexperienced medical students and professionals. Using simulated patient models, medical students can practice a procedure or diagnosis a number of times. Replacing human for safety is though the biggest advantage of simulation, the other important advantage is in better training of the students. When working on simulators, students concentrate only on the essential element which has been modeled and are able to ignore the rest. They learn without any hesitation and gain better confidence in handling real patients.

Computer simulations have the advantage of allowing the student to make judgments as well as errors. The process of iterative learning through assessment, evaluation, decision making and error correction creates a much stronger learning environment then the passive instructions.

Many medical simulators comprise of a plastic simulated model of the relevant anatomy connected to a computer. These are generally life size models that respond to injected drugs and are programmed to create simulations of life-threatening emergencies. In other simulators, computer graphic techniques are employed to visualize the components and procedure. Simulators are also being used in the development of tools for diagnosis and treatment of cancer like diseases.

Earlier, physical models made of clay or stone were used to demonstrate the clinical features of disease states and their effects on human. Then came the active models that attempted to reproduce the living anatomy or physiology. More recently interactive models have been developed that respond to actions taken by a student or physician.

1.23 Exercises

1.1 Name two or three of the main entities, attributes, activities, events and state variables which are to be considered for simulating the operation of,

(*a*) Post office

(*b*) Cafeteria

(*c*) A hospital OPD

(*d*) A garment store

(*e*) An automobile assembly line

(*f*) A traffic crossing

(*g*) A bus stand.

1.2 What are the events and activities associated with parking your car in a paid parking ?

1.3 Identify minimum five endogenous and five exogenous activities associated with a production shop.

1.4 Give five examples of each of the following :

(*a*) Continuous system

(*b*) Discrete system

(*c*) Stochastic system

(*d*) Physical model

(*e*) Mathematical model.

1.5 List the entities, attributes, activities and state variables in the working of your college workshop.