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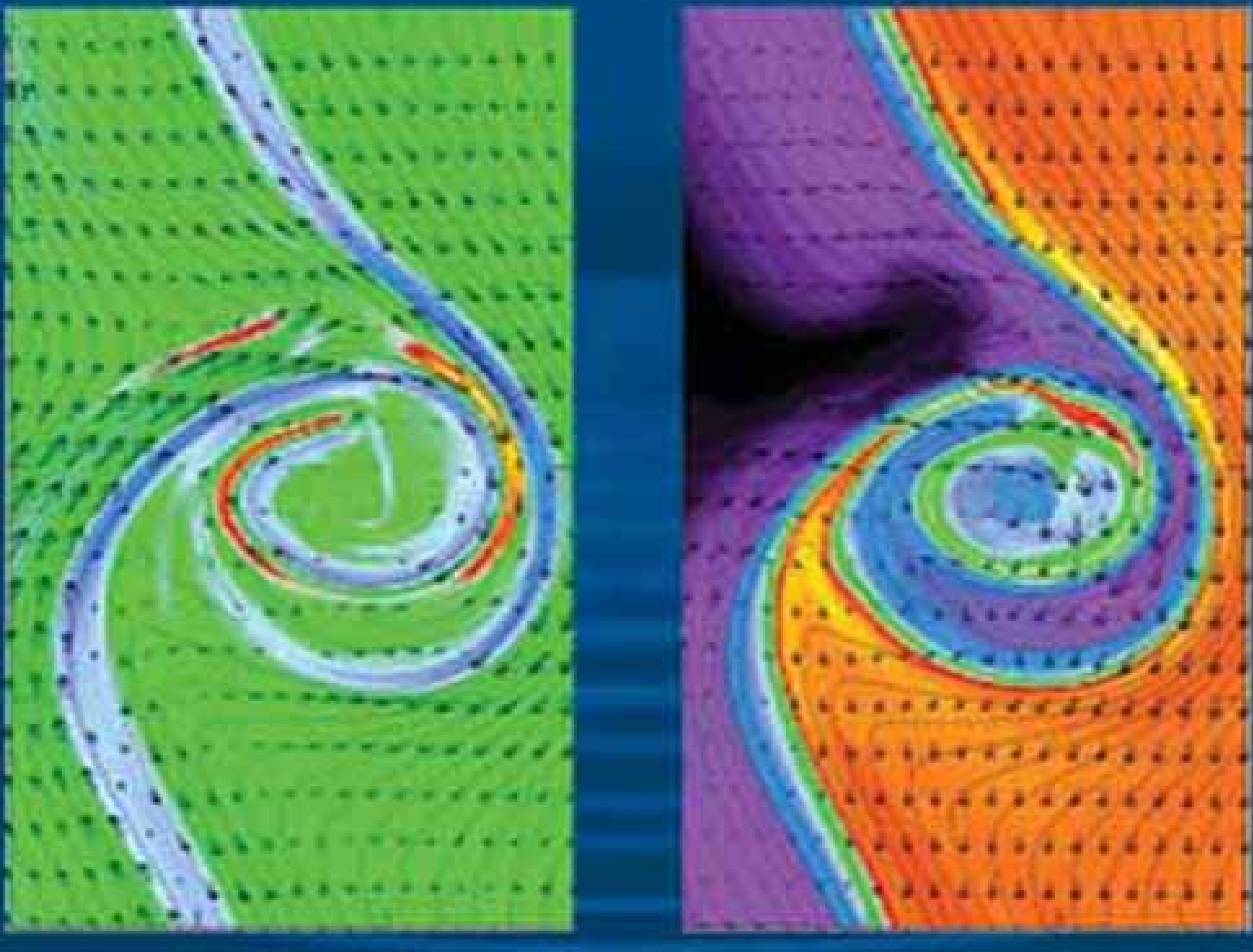
SYSTEM SIMULATION



D.S. HIRA

S. CHAND

SYSTEM SIMULATION

[For B.E./B.Tech. and M. Tech. students of various branches of Engineering as well as B.B.A. and M.B.A. students of all Indian Universities]

D.S. HIRA
Director Shaheed Udham Singh
College of Engineering and Technology
Tangori (Mohali)
Punjab

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- Kailash Residency, Plot No. 4B, Bottle House Road, Shankar Nagar, **Raipur.** Ph. 09981200834 raipur@schandgroup.com

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PREFACE TO THE SECOND EDITION

The objective of the book, in second addition also, remains the same, of giving a sound knowledge to the readers of the fundamental aspects of this important technique of system simulation, which is used in the analysis of complex systems. The emphasis continues to be on the discrete event simulation, which finds applications in a wide range of real life situations and is a part of the curriculum of engineering and management disciplines of many universities. In the revised addition, a number of important topics have been added, especially on the input and output data analysis and General Purpose Simulation System (GPSS) language.

The text now comprises of eleven chapters.

Chapter 1, which covers the basic concepts of system, system modeling and simulation, has been expanded to include the details of types of models, the components of the system and application of simulation in design, training, education, healthcare and computer science.

Chapter 2 on Monte Carlo Method, chapter 3 on simulation of continuous systems and Chapter 4 on generation of random numbers, remain almost the same, with a few additional examples and exercises in each.

Chapter 5 has been renamed as 'Statistical Considerations' and very useful material on central limit theorem, has been incorporated in this chapter.

Chapter 6 on simulation of queuing systems and chapter 7 on simulation of inventory systems have been provided with more solved examples, while Chapter 8 on simulation of PERT has been retained as it is.

Chapter 9 has been totally remodeled and named 'Design of Simulation Experiments and Output Analysis'. In addition to covering the verification and validation of models, design of simulation experiment and variance reduction techniques, a thorough treatment has been given to Metamodelling, regression analysis and ANOVA.

Chapter 10, in this edition, has been devoted to the simulation languages. Effort has been made to provide sufficient inputs on various types of simulation tools. A detailed treatment has been given to GPSS, a very important discrete event simulation tool.

Chapter 11, which was Chapter 10 in the first edition, remains the same. A number of practical applications of the simulation technique has been discussed in this chapter. The solved problems and exercises given in this chapter can be taken up as the project work by the students.

It is expected that this revised edition of the book will be a very useful learning material for the students of engineering and management of various universities. A good practice of the given exercises will prepare the readers to handle the real life situations with increased confidence.

Author is thankful to Prof. Mandeep Kaur Hundal of GNDU Regional Campus Jalandhar for providing valuable help in translating the conceptual models into computer simulations and to Prof. Preetinder Kaur of SUSCET Tangori for providing valuable inputs on GPSS. Thanks are also due to Mr. Sandeep Jain of SUSCET Tangori for assistance in data and text entry of the additional topics of manuscript. Last but not the least; author is thankful to Mrs. Manjit Kaur Hira for her constant encouragement, motivation and moral support.

D.S. Hira

CONTENTS

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

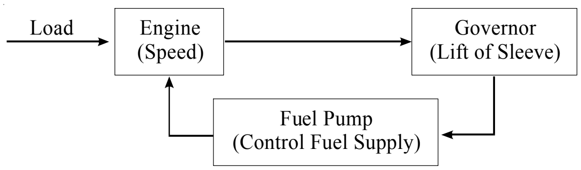

Fig. 1.1

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.

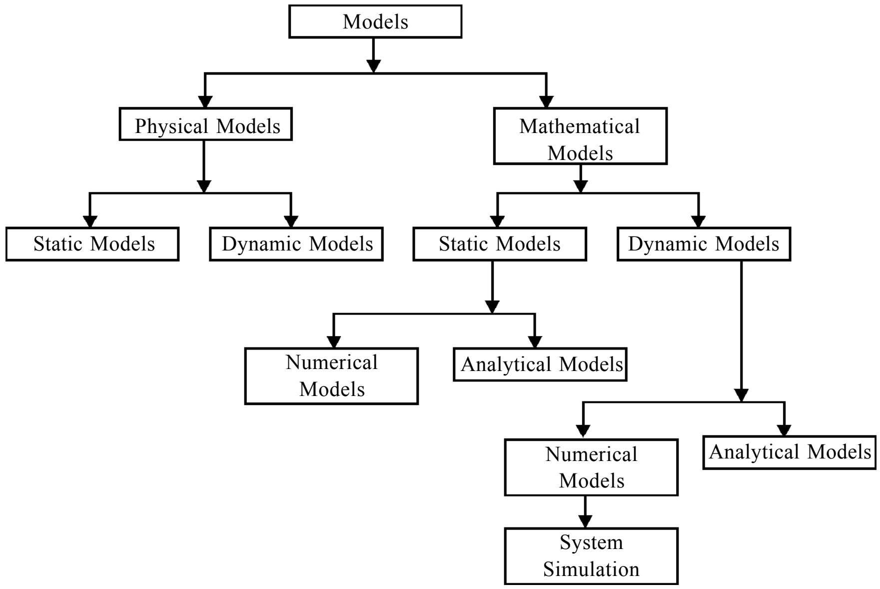

Fig. 1.2 Types of models

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

System Simulation