Chapter 1
Introduction to Simulation

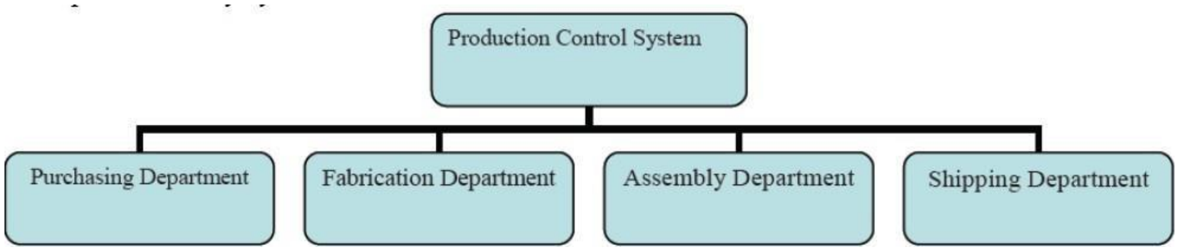
1.1 What is simulation?

Simulation is the imitation of the operation of a real-world process or system over time. Simulation involves the generation of an artificial history of the system, and the observation of that artificial history to draw inferences concerning the operating characteristics of the real system that is represented. Simulation is the numerical technique for conducting experiments on digital computer, which involves logical and mathematical relationships that interact to describe the behavior and the structure of a complex real world system over extended period of time. The process of designing a model of a real system, implementing the model as a computer program, and conducting experiments with the model for the purpose of understanding the behavior of the system, or evaluating strategies for the operation of the system.

1.2. System Concepts

A system is defined as a group of objects that are joined together in some regular interaction or interdependence for the accomplishment of some task. For example: *Production system for manufacturing automobiles.* A system is usually considered as a set of inter–related factors, which are described as entities activities and have properties or attributes. Processes that cause system changes are called activities. The state of a system is a description of all entities, attributes and the activities at any time.

Example: A factory system shown as follows:



1.3. Components of system

1.3.1. Entity, attribute and activities

An **entity** represents an object that requires explicit definition. An entity can be dynamic in that it moves through the system, or it can be static in that it serves other entities. In the example, the customer is a dynamic entity, whereas the bank teller is a static entity. An entity may have **attributes** that pertain to that entity alone. Thus, attributes should be considered as local values. Inthe example, an attribute of the entity could be the time of arrival. Attributes of interest in one investigation may not be of interest in another investigation. Thus, if red parts and blue parts are being manufactured, the color could be an attribute. Processes that cause system changes are called **activities and events.** In the bank example, events include the arrival of a customer for service at the bank, the beginning of service for a customer, and the completion of a service. There are both internal and external events, also called endogenous and exogenous events, respectively.

Example

System	Entities	Attributes	Activities
Traffic	Cars, bus, pedestrian	Speed, model	Driving, walking
Bank	Customer	Balance	Depositing, arrival of costomer, ….
Supermarket	Customers	Shopping list	Checking_out, …..

For instance, an endogenous event in the example is the beginning of service of the customer since that is within the system being simulated. An exogenous event is the arrival of a customer for service since that occurrence is outside of the simulation.

- Activity – some action performed by an entity
  - Represented by a time period of specified length
  - *Example: making a deposit*

Event – "instantaneous occurrence that might change the state of the system"

- Endogenous event – occurs within the system
- Exogenous event – occurs outside in the *environment*
  - can still affect the system

Examples:

Arrival of a new customer

Completed service of a customer

1.3.2. State variables

The state of a system is defined to be that collection of variables necessary to describe the system at any time, relative to the objectives of the study. In the study of a bank, possible state variables are the number of busy tellers, the number of customers waiting in line or being served, and the arrival time of the next customer. So the system state variables are the collection of all information needed to define what is happening within the system to a sufficient level (i.e., to attain the desired output) at a given point in time.

System	*Entities*	*Attributes*	*Activities*	*Events*	*State Variables*
Banking	Customers	Checking-account 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 (busy, idle, or down)
Communications	Messages	Length; destination	Transmitting	Arrival at destination	Number waiting to be transmitted
Inventory	Warehouse	Capacity	Withdrawing	Demand	Levels of inventory; backlogged demands

1.3.3. Open System/Close System

A system with exogenous activities is considered as open system and a system with strict endogenous activities is called a closed system.

1.4 System Environment

The external components which interact with the system and produce necessary changes are said to constitute the system environment. In modeling systems, it is necessary to decide on the boundary between the system and its environment. This decision may depend on the purpose of the study.
Example: In a factory system, the factors controlling arrival of orders may be considered to be outside the factory but yet a part of the system environment. When, we consider the demand and supply of goods, there is certainly a relationship between the factory output and arrival of orders. This relationship is considered as an activity of the system.

Endogenous System

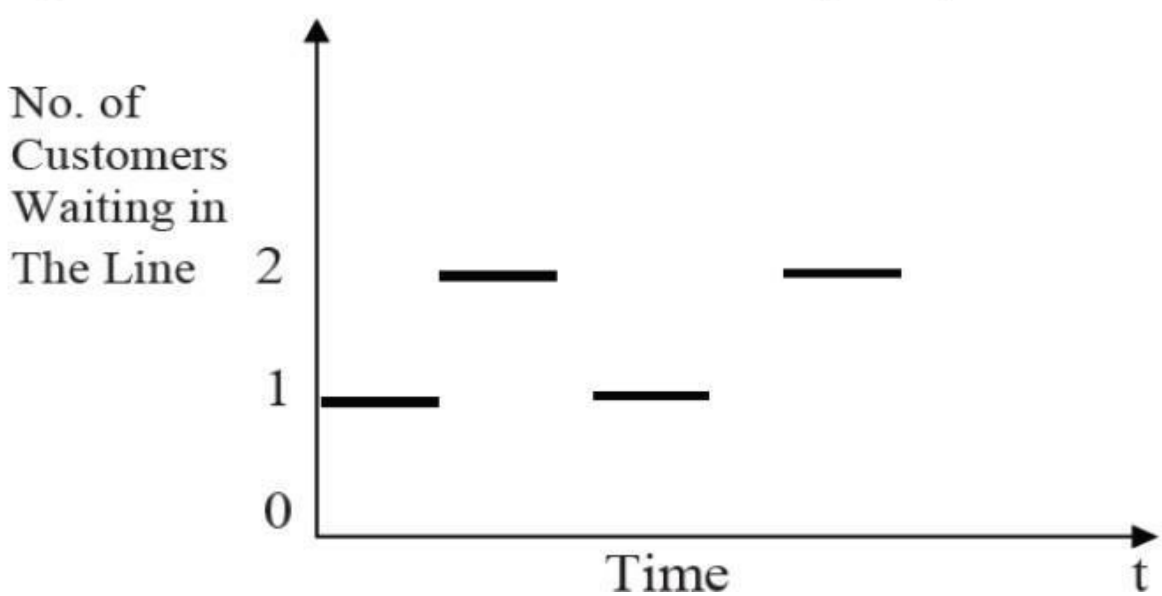
The term endogenous is used to describe activities and events occurring within a system.
Example: Drawing cash in a bank.

Exogenous System

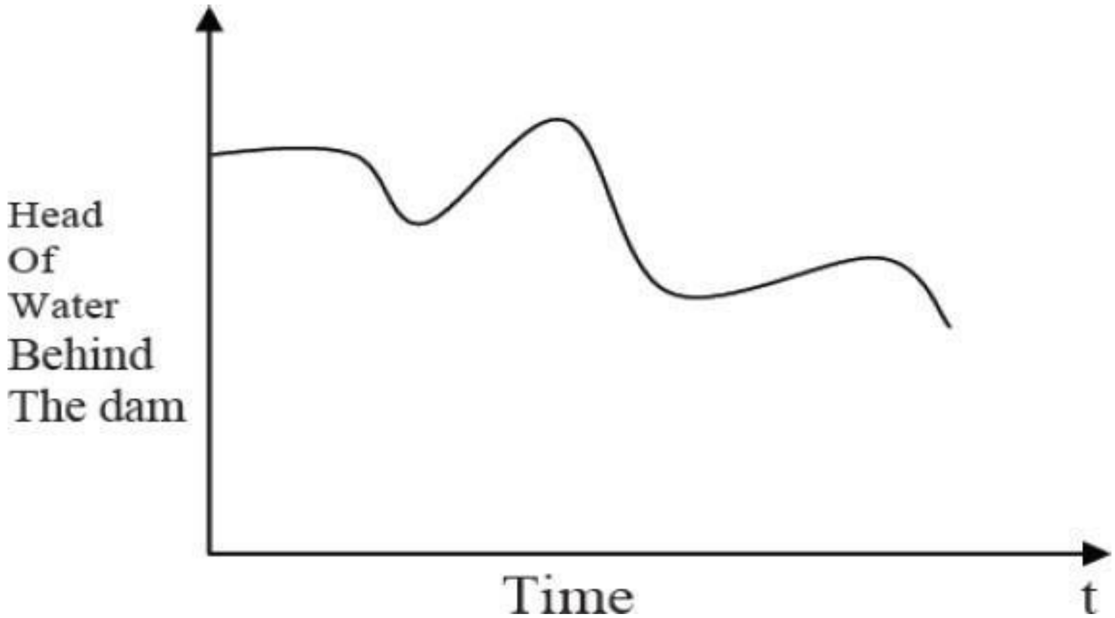
The term exogenous is used to describe activities and events in the environment that affect the system. Example: Arrival of customers.

1.5. Discrete and continuous system

Discrete system is one in which the state variables changes only at a discrete set of time. For example: banking system in which no of customers (state variable) changes only when a customer arrives or service provided to customer i.e. customer depart form system.
The figure below show how no of customer changes only at discrete points in time.



Continuous system is one in which the state variables change continuously over time. For example, during winter seasons level of which water decreases gradually and during rainy season level of water increase gradually. The change in water level is continuous. The figure below shows the change of water level over time.



1.6. System Modeling

A model is defined as a representation of a system for the purpose of studying the system. It is necessary to consider only those aspects of the system that affect the problem under investigation. These aspects are represented in a model, and by definition it is a simplification of the system. The aspect of system that affect the problem under investigation, are represented in a model of the system. Therefore model is the simplification of the real system.

There is no unique model of a system. Different models of the same system will be produced by different system analysts who are interested in different aspect of system.

The task of deriving a model of a system may be divided broadly into two subtasks: Establishing model parameter and supplying data. Establishing model structure determines system boundary and identifies the entities, attributes, activities and events of a system. Supplying data provides value contained an attribute and define relationships involved in the activities.

1.7. Types of Model

Mathematical and Physical Model
Static Model
Dynamic Model
Deterministic Model
Stochastic Model
Discrete Model
Continuous Model

Static Model

Static models can only show the values that the system attributes value does not change over time. Example: Scientist has used models in which sphere represents atom, sheet of metal to connect the sphere to represent atomic bonds. Graphs are used to model the various system based on network. A map is also a kind of graph. These models are sometimes said to be iconic models and are of kind static physical models.

Dynamic Model
Dynamic models follow the changes over time that result from system activities. The mechanical and electrical systems are the example of dynamic system. Generally, dynamic models involve the computation of variable value over time and hence they are represented by differential equations.

Analytical Models:
In mathematical model, we can differentiate the model on the basis of solution technique used to solve the model. Analytical technique means using deductive reasoning of mathematical theory to solve a model. Such models are known as analytical model.

Numerical models
Numerical models involve applying computational process to solve equations. For example: we may solve differential equation numerically when the specific limit of variable is given. The analytical methods to produce solution may take situation numerical methods are preferred.

Deterministic Model
It contains no random variables. They have a known set of inputs which will result in a unique set of outputs. Ex: Arrival of patients to the Dentist at the scheduled appointment time.

Stochastic Model
Has one or more random variable as inputs. Random inputs leads to random outputs. Ex:
Simulation of a bank involves random inter-arrival and service times.

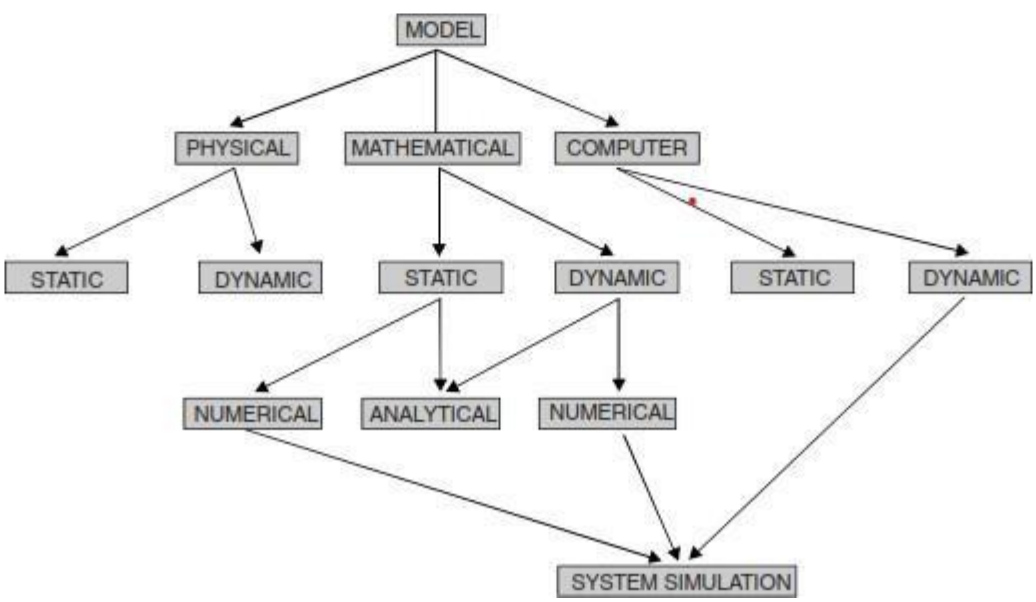


Figure: Different types of models.

1.7.1. Static Physical Model

The best known examples of physical models are scale models. In shipbuilding, making a scale model provides a simple way of determining the exact measurements of the plates of determining the exact measurements of the plates covering the hull, rather than having to produce drawings of complicated, three-dimensional shapes. Scientists have used models in which spheres represent atoms, and rods or specially shaped sheets of metal connect the spheres to represent atomic bonds.

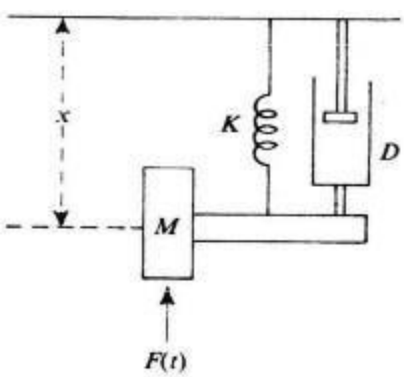
Scale models are also used in wind tunnels and water tanks. Scale models are also used in wind tunnels and water tanks in the course of designing aircraft and ships. Although air is blown over the model, or the model is pulled through the water, these are static physical models because the measurements that are taken represent attributes of the system being studied under one set equilibrium conditions system being studied under one set, equilibrium conditions. In this case, the measurements do not translate directly into system attribute values.

Well known laws of similitude are used to convert measurements on the scale model to the values that would occur in the real system. Sometimes a static physical model is used as a means of solving equations with particular boundary conditions.

There are many examples in the field of mathematical physics where the same equations apply to different physical phenomena. For example, the flow of heat and the distribution of electric charge through space can be related by common equations.

1.7.2. Dynamic Physical Model

Dynamic physical models rely upon an analogy between the system being studied and some other system of a different nature, the analogy usually depending upon an underlying similarity in the forces governing the behavior of the systems. To illustrate this type of physical model, consider the two systems shown in following figures.



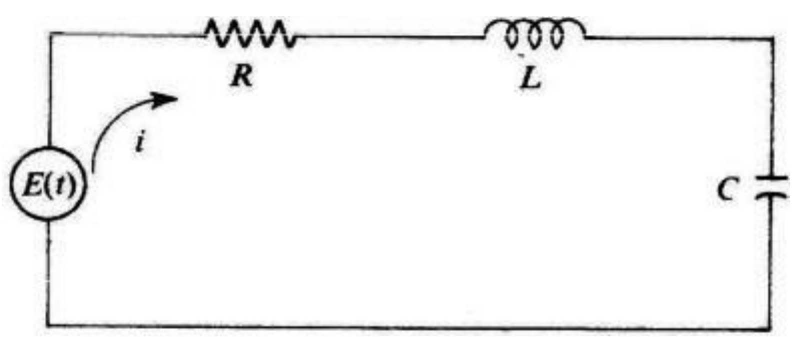


Figure a: Mechanical System **Figure b: Electrical System**

The Figure b. represents a mass that is subject to an applied force F(t) varying with time, a spring whose force is proportional to its extension or contraction, and a shock absorber that exerts a damping force proportional to the absorber that exerts a damping force proportional to the velocity of the mass. The system might for example represent the suspension of an automobile wheel when the automobile body is assumed to be immobile in a vertical direction.
It can be shown that the motion of the system is described by the following differential equation:

$$M\ddot{x} + D\dot{x} + Kx = KF(t)$$

Where,

x is the distance moved,

M is the mass,

K is the stiffness of the spring,

D is the damping factor of the shock absorber

- Figure 3. represents an electrical circuit with an inductance L, a resistance R, and a capacitance C, connected in series with a voltage source that varies in time according to the function E(t). If q is the charge on the capacitance, it can be shown that the behavior of the circuit is governed by the following differential equation:

$$L\ddot{q} + R\dot{q} + \frac{q}{C} = \frac{E(t)}{C}$$

- Inspection of these two equations shows that they have exactly the same form and that the following equivalences occur between the quantities in the two systems:

Displacement x	Charge q
Velocity $\dot{x}$	Current $I(=\dot{q})$
Force F	Voltage E
Mass M	Inductance L
Damping factor D	Resistance R
Spring stiffness K	1/Capacitance $1/C$

The mechanical system and the electrical system are analogs of each other, and the performance of either can be studied with the other. In practice, it is simpler to modify the electrical system than to change the mechanical system, so it is more likely that the electrical system will have been built to study the mechanical system.

1.7.3. MATHEMATICAL MODEL

Most of the systems can in general be transformed into mathematical equations. These equations are called the mathematical model of that system. A static model gives relationships between the system attributes when the system is in equilibrium. Mathematical model of a system, in equilibrium is called a ***Static Mathematical Model.*** If mathematical model of a system are function of time, such model is ***dynamic mathematical model***, such as model of Wheel Suspension System.

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Static Mathematical Models

If mathematical model does not involve time i.e., system does not change with time, it is called a static mathematical model of the system.

Example: Static Market Model

Generally there should be a balance between the supply and demand of any product in the market. Supply increases if the price is higher. This is because shopkeeper gets more commission on that product and tries to push the product to the customers even if quality is not excellent. Customer generally feels that more cost means better quality. But on the other hand demand decreases with the increase of price. Aim is to find the optimum price with which demand can match the supply. Let us model this situation mathematically. If we denote price by P, supply by S and demand by D, and assuming the price equation to be linear we have

$$\begin{aligned} D &= a - bP \\ S &= c + dP \qquad \ldots(a) \\ S &= D \end{aligned}$$

In the above equations, a, b, c, d are parameters computed based on previous market data. $S = D$ says supply should be equal to demand so that market price should accordingly be adjusted. Let us take values of $a = 500$, $b = 2000$, $c = -50$ and $d = 1500$. Value of c is taken negative, since supply cannot be possible if price of the item is zero. In this case no doubt equilibrium market price will be

$$P = \frac{a-c}{b+d} = \frac{550}{3500} = 0.1571$$

$$S = 186$$

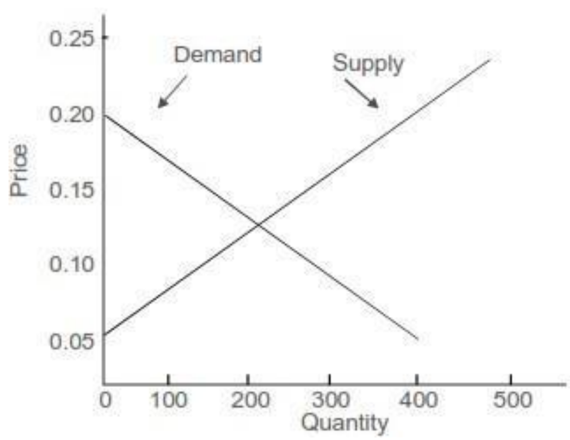


Figure a: Market Model

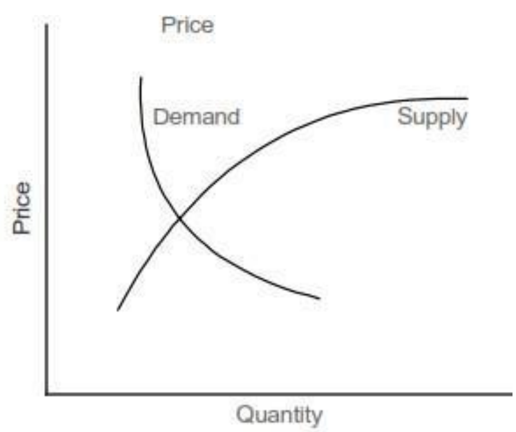


Figure b: Non-Linear Market Model

In this model we have taken a simplistic linear case but equation (a) may be complex. In that case solution may not be so simple. More usually, the demand and supply are depicted by curves with slopes downward and upward respectively (Figure b). It may not be possible to express the relationships by equations that can be solved easily. Some numerical or graphical methods are used to solve such relations. In addition, it is difficult to get the values of the coefficients of the model. Observations over the extended period of time, however, will establish the slopes (that is values of b and d) in the neighbourhood of the equilibrium points. These values will often fluctuate under the global and local economic conditions.

Dynamic Mathematical Models

- A dynamic mathematical model allows the changes of system attributes to be derived as a function of time.
- The derivation may be made with an analytical solution or with a numerical computation, depending upon the complexity of the model.
- The equation that was derived to describe the behavior of a car wheel is an example of a dynamic mathematical model; in this case, an equation that can be solved analytically.

$$M\frac{d^2x}{dt^2} + D\frac{dx}{dt} + Kx = KF(t)$$

- It is customary to write the equation in the form

$$\frac{d^2x}{dt^2} + 2\zeta\omega\frac{dx}{dt} + \omega^2 x = \omega^2 F(t)$$

where $2\zeta\omega = D/M$ and $\omega^2 = K/M.$

- Expressed in this form, solutions can be given in terms of the variable wt. Figure.5 shows how x varies in response to a steady force applied at time t = 0 as would occur, for instance, if a load were suddenly placed on the automobile.
- Solutions are shown for several values of ζ , and it can be seen that when ζ is less than 1, the motion is oscillatory.

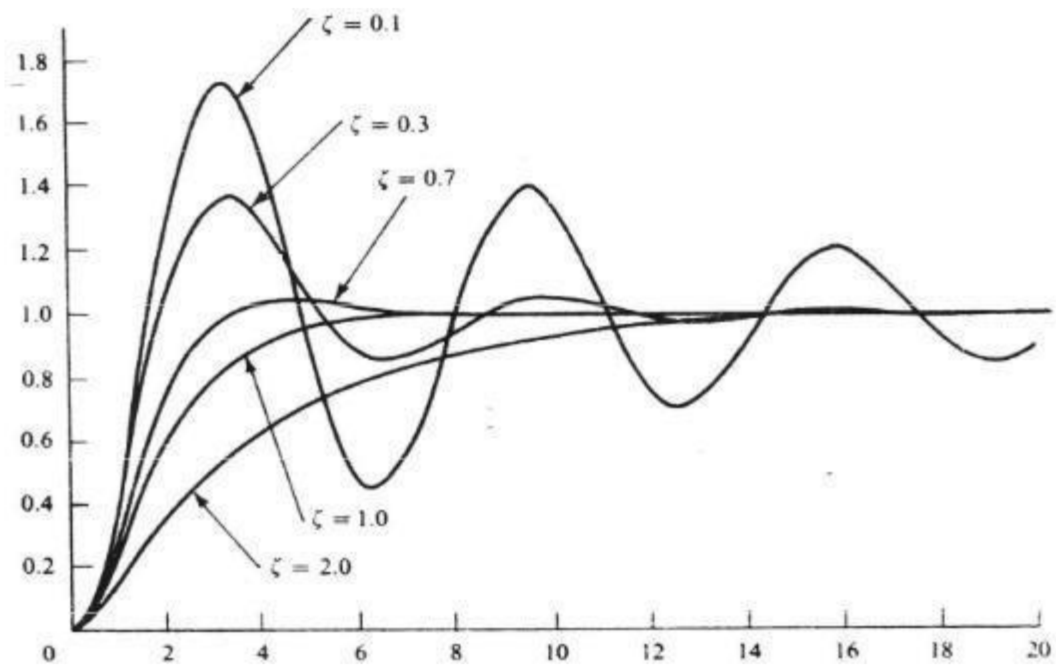


Figure 5: Linear Market Model

- The factor ζ is called the damping ratio and, when the motion is oscillatory, the frequency of oscillation is determined from the formula.

$$\omega = 2\pi f$$

- Where f is the number of cycles per second.
- Suppose a case is selected is representing a satisfactory frequency and damping. The relationship given above between ζ , ω ,M, k and D show how to select the spring and shock absorber to get that type of motion. For example the condition for the motion to occur without oscillation requires that $\zeta \geq 1$. It can be deduced from the definition of that the condition requires that $D^2 \geq 4MK$.

1.7.4. Distributed lag model

Models that have the properties of changing only at fixed intervals of time, and of basing current values of the variables on other current values and values that occurred in previous intervals, are called *distributed lag models.* These are a type of dynamic models, because time factor is involved in them. They are extensively used in econometric studies where the uniform steps correspond to a time interval, such as a month or a year, over which some economic data are collected. As a rule, these models consist of linear, algebraic equations. They represent a continuous system, but the one in whichdata is only available at fixed points in time.

As an example, consider the following simple dynamic mathematical model of the national economy.

Let,

C be consumption,
I be investment,
T be taxes,
G be government expenditure and *Y* be national income.

Then

$$\left.\begin{aligned} C &= 20 + 0.7(Y - T) \\ I &= 2 + 0.1Y \\ T &= 0 + 0.2Y \\ Y &= C + I + G \end{aligned}\right\} \qquad \ldots\ldots\ldots(1)$$

All quantities are expressed in billions of rupees.

………..(2)

………..(2)

This is a static model, but it can be made dynamic by picking a fixed time interval, say one year, and expressing the current values of the variables in terms of values of the previous year. Any variable that appears in the form of its current value and one or more previous year's values is called *lagged variables*. Value of the previous year is denoted by the suffix with-1.

The static model can be made dynamic by lagging all the variables, as follows;

$$\left.\begin{aligned} C &= 20 + 0.7(Y_{-1} - T_{-1}) \\ I &= 2 + 0.1Y_{-1} \\ T &= 0.2Y_{-1} \\ Y &= C_{-1} + I_{-1} + G_{-1} \end{aligned}\right\}$$

In these equations if values for the previous year (with –1 subscript) is known, then values for the current event can be computed. Taking these values as the input, values for the next year can also be computed. In equation (2) we have four equations in five unknown variables.

It is however not necessary to lag all the variable like it is done in equation (2). Only one of the variables can be lagged and others can be expressed in terms of this variable. We solve equation for Y in equation (1) as

$$\begin{aligned} Y &= 20 + 0.7(Y - 0.2Y) + I + G \\ &= 20 + 0.56Y + I + G \end{aligned}$$

or $$Y = 45.45 + 2.27(I + G)$$

Thus we have,

$$\left.\begin{aligned} I &= 2.0 + 0.1Y_{-1} \\ Y &= 45.45 + 2.27(I + G) \\ T &= 0.2Y \\ C &= 20 + 0.7(Y - T) \end{aligned}\right\} \qquad \text{...........(3)}$$

In equations (3) only lagged parameter is *Y*. Assuming that government expenditure is known for the current year, we first compute *I*. Knowing *I* and *G*, *Y* and *T* for the current year is known, and thus *C* is computed from the last equation. In this problem, lagged model is quite simple and can be computed with hand calculator. But national economic models are generally not that simple and require long computations with number of parameters.

Advantages of distributed lag model

- Simple to understand and can be computed by hand, computers are extensively used to run them.
- There is no need for special programming language to organize simulation task.

1.8. Principles used in Modeling

It is not possible provide rule by which models are built. But a number of guidelines can be stated. The different viewpoints from which we can judge whether certain info. Should be included as excluded in models are:

Block –Building: The description of system should be organized as a sequence of blocks. It simplifies the interaction between block within system. Then it will be easy to describe the whole system in terms of interaction between the block and can be represented graphically as simple block diagram. For example:-the block of factory system. Fig: Block diagram of factory system

Relevance: The model should only include relevant information. For example, if the factory system study aims to compare the efficient of different operating rules efficiency it is not relevant to consider the mining of employee as an activity. Irrelevant information should not include despite of being no harm because it increases the complexity of model and takes more time and effort to solve model.

Accuracy: The gathered information should be accurate as well. For example in aircraft system the accuracy as movement of the aircraft depends upon the representations of airframe such as a rigid body.

Aggregation: It should be considered that to which numbers of individual entities can be grouped into a block. For example in factory system, different department are grouped together handled by production manger.

1.9. Steps on simulation Study

Problem formulation

Every study begins with a statement of the problem, provided by policy makers. Analyst ensures it is clearly understood. If it is developed by analyst policy makers should understand and agree with it.

Setting of objectives and overall project plan

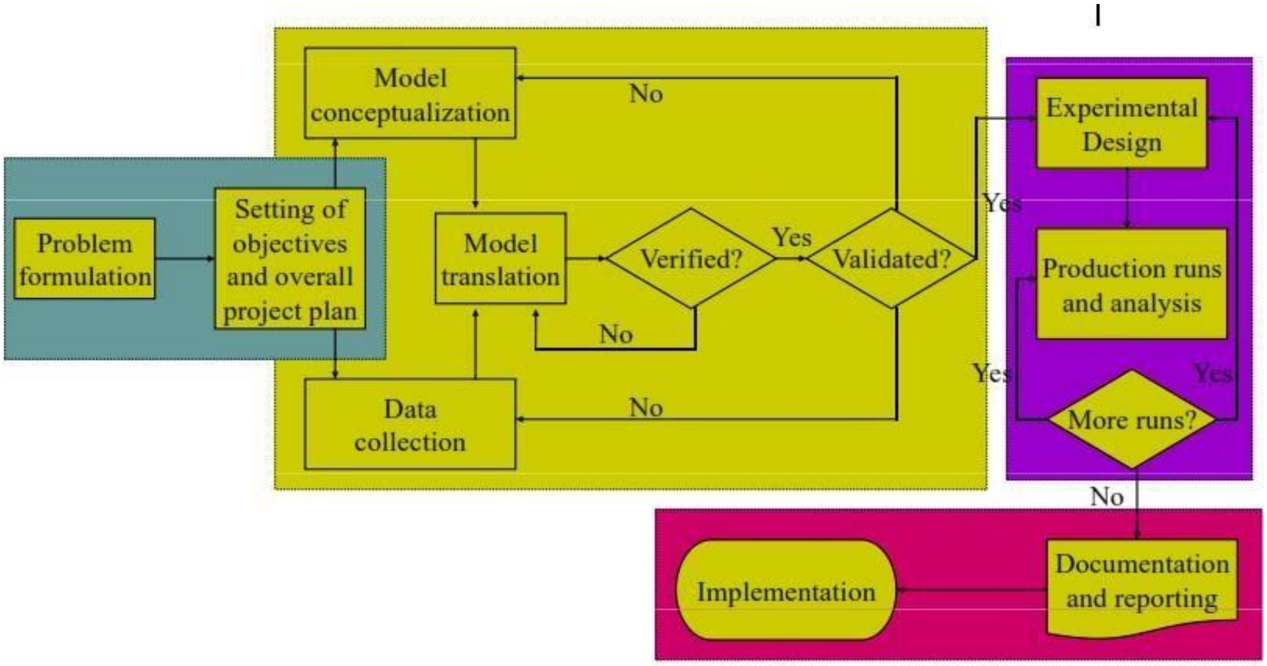
The objectives indicate the questions to be answered by simulation. At this point a determination should be made concerning whether simulation is the appropriate methodology. Assuming it is appropriate, the overall project plan should include

- A statement of the alternative systems
- A method for evaluating the effectiveness of these alternatives
- Plans for the study in terms of the number of people involved
- Cost of the study
- The number of days required to accomplish each phase of the work with the anticipated results.

Model conceptualization

The construction of a model of a system is probably as much art as science. The art of modeling is enhanced by ability:

- To abstract the essential features of a problem.
- To select and modify basic assumptions that characterizes the system.
- To enrich and elaborate the model until a useful approximation results. Thus, it is best to start with a simple model and build toward greater complexity. Model conceptualization enhances the quality of the resulting model and increases the confidence of the model user in the application of the model.



Data collection
There is a constant interplay between the construction of model and the collection of needed input data. It is done in the early stages. Objective kinds of data are collected.

Model translation
Real-world systems result in models that require a great deal of information storage and computation. It can be programmed by using simulation languages or special purpose simulation software. Simulation languages are powerful and flexible. Simulation software models development time can be reduced.

Verified
It pertains to the computer program and checking the performance. If the input parameters and logical structure are correctly represented, verification is completed.

Validated
It is the determination that a model is an accurate representation of the real system. It is achieved through calibration of the model. The calibration of model is an iterative process of comparing the model to actual system behavior and the discrepancies between the two.

Experimental Design
The alternatives that are to be simulated must be determined. Which alternatives to simulate may be a function of runs? For each system design, decisions need to be made concerning

· Length of the initialization period
· Length of simulation runs
· Number of replication to be made of each run

Production runs and analysis
They are used to estimate measures of performance for the system designs that are being

simulated.

More runs
Based on the analysis of runs that have been completed, the analyst determines if additional runs are needed and what design those additional experiments should follow.

Documentation and reporting
Two types of documentation:
· Program documentation
· Process documentation
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.

Process documentation
It 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.

Implementation
Success depends on the previous steps. If the model user has been thoroughly involved and understands the nature of the model and its outputs, likelihood of a vigorous implementation is enhanced. The simulation model building can be broken into 4 phases.

Phase of Simulation Study
I Phase
· Consists of steps 1 and 2
· It is period of discovery/orientation
· The analyst may have to restart the process if it is not fine-tuned
· Recalibrations and clarifications may occur in this phase or another phase.
II Phase
· Consists of steps 3,4,5,6 and 7
· A continuing interplay is required among the steps
· Exclusion of model user results in implications during implementation
III Phase
· Consists of steps 8,9 and 10
· Conceives a thorough plan for experimenting
· Discrete-event stochastic is a statistical experiment
· The output variables are estimates that contain random error and therefore proper statistical analysis is required.
IV Phase

· Consists of steps 11 and 12

· Successful implementation depends on the involvement of user and every steps successful completion.

When simulation is appropriate Tool?

The availability of special-purpose simulation languages, massive computing capabilities at a decreasing cost per operation, and advances in simulation methodologies have made simulation one of the most widely used and accepted tools in operations research and systems analysis.

Simulation can be used for the following purposes:

1. Simulation enables the study of, and experimentation with, the internal interactions of a complex system, or of a subsystem within a complex system.
2. Informational, organizational, and environmental changes can be simulated, and the effect of these alterations on the model's behavior can be observed.
3. The knowledge gained in designing a simulation model may be of great value toward suggesting improvement in the system under investigation.
4. By changing simulation inputs and observing the resulting outputs, valuable insight may be obtained into which variables are most important and how variables interact.
5. Simulation can be used to experiment with new designs or policies prior to implementation, so as to prepare for what may happen.
6. Simulation can be used to verify analytic solutions.
7. By simulating different capabilities for a machine, requirements can be determined.
8. Simulation models designed for training allow learning without the cost and disruption of on-the-job learning.

When the simulation is not appropriate?

To recognize if simulation is the correct approach to solving a particular problem, four items should be evaluated before deciding to conduct the study:

Type of Problem: If a problem can be solved by common sense or analytically, the use of simulation is unnecessary. Additionally, using algorithms and mathematical equations may be faster and less expensive than simulating. Also, if the problem can be solved by performing direct experiments on the system to be evaluated, then conducting direct experiments may be more desirable than simulating.

Availability of Resources: People and time are the determining resources for conducting a simulation study. An experienced analyst is the most important resource since such a person has the ability and experience to determine both the model's appropriate level of detail and how to verify and validate the model. Without a trained simulator, the wrong model may be developed which produces unreliable results. Additionally, the allocation of time should not be so limited so as to force the simulator to take shortcuts in designing the model. The schedule should allow enough time for the implementation of any necessary changes and for verification and validation to take place if the results are to be meaningful.

Costs: Cost considerations should be given for each step in the simulation process, purchasing simulation software if not already available, and computer resources. Obviously if these costs exceed the potential savings in altering the current system, then simulation should not be pursued.

***Availability of Data*:** The necessary data should be identified and located, and if the data does not exist, then the data should be collectible. If the data does not exist and cannot be collected, then continuing with the simulation study will eventually yield unreliable and useless results. The simulation output cannot be compared to the real system's performance, which is vital for verifying and validating the model.

Advantages of simulation

1. Simulation can also be used to study systems in the design stage.
2. Simulation models are run rather than solver.
3. New policies, operating procedures, decision rules, information flow, etc can be explored without disrupting the ongoing operations of the real system.
4. New hardware designs, physical layouts, transportation systems can be tested without committing resources for their acquisition.
5. Hypotheses about how or why certain phenomena occur can be tested for feasibility.
6. Time can be compressed or expanded allowing for a speedup or slowdown of the phenomena under investigation.
7. Insight can be obtained about the interaction of variables.
8. Insight can be obtained about the importance of variables to the performance of the system.
9. Bottleneck analysis can be performed indication where work-in process, information materials and so on are being excessively delayed.
10. A simulation study can help in understanding how the system operates rather than how individuals think the system operates.
11. "what-if" questions can be answered. So it is useful in the design of new systems.

Disadvantage of simulation

1. Model building requires special training.
2. Simulation results may be difficult to interpret.
3. Simulation modeling and analysis can be time consuming and expensive.
4. Simulation is used in some cases when an analytical solution is possible or even preferable.

Applications of Simulation

Manufacturing Applications

1. Analysis of electronics assembly operations
2. Design and evaluation of a selective assembly station for high precision scroll compressor shells.
3. Comparison of dispatching rules for semiconductor manufacturing using large facility models.
4. Evaluation of cluster tool throughput for thin-film head production.
5. Determining optimal lot size for a semiconductor backend factory.
6. Optimization of cycle time and utilization in semiconductor test manufacturing.
7. Analysis of storage and retrieval strategies in a warehouse.
8. Investigation of dynamics in a service oriented supply chain.
9. Model for an Army chemical munitions disposal facility.

Semiconductor Manufacturing

1. Comparison of dispatching rules using large-facility models.
2. The corrupting influence of variability.
3. A new lot-release rule for wafer fabrication.
4. Assessment of potential gains in productivity due to proactive retied management.
5. Comparison of a 200 mm and 300 mm X-ray lithography cell.
6. Capacity planning with time constraints between operations.

Military Applications

1. Modeling leadership effects and recruit type in a Army recruiting station.
2. Design and test of an intelligent controller for autonomous underwater vehicles.
3. Modeling military requirements for non war fighting operations.
4. Multi trajectory performance for varying scenario sizes.
5. Using adaptive agents in U.S. Air Force retention.

Hybrid Simulation: For most studies, the system under study is clearly either of continuous or discrete nature and it is the determining factor in deciding whether to use an analog or digital computer for system simulation. If the system being simulated is an interconnection of continuous and discrete subsystem, then such system simulation is known as hybrid simulation. Such hybrid system can be digital computer being linked together. Hybrid simulation required high speed converters to transform signals from analog to digital from and vice –versa.

Real time simulation: In real time simulation, actual device (which are part of a system) are used in conjunction with either digital computer or hybrid computer. It provides the simulation of the points of systems that do not exist or that cannot be easily used in an experiment i.e. the basic idea of real time simulation is „uses the actual part if they are appropriate to use in experiment otherwise use the simulation of the points of the system‟.

A well-known examples is "simulation to train pilots". It uses the devices for training pilots by giving them the impression that is at the control of an aircraft. It requires real time simulator of the plane its control system, the weather and other environmental conditions. Sometimes, real time simulation also refers to a computer model of a physical system that can execute at the same rate as actual system can. For example: if a machine takes 10 minutes to fill a tank in real world, the simulation also would take 10 minutes. Real time simulation of an engineering system becomes possible when we replace physical device with virtual device.