Chapter 1
Introduction to Simulation

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.

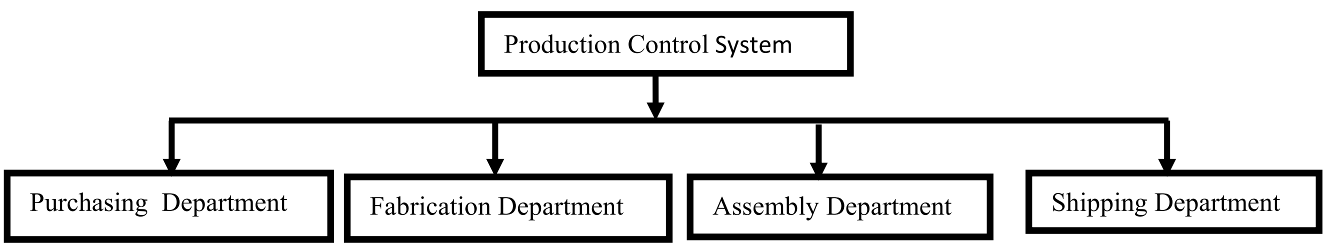
Simulation is the numerical technique for conducting experiments on digital computer, which involves logical and mathematical relationships that interact to describe the behavior and the structure of a complex real world system over extended period of time.

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.

2. System Concepts

A system is defined as a group f 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:

Components of system

2.1 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. In the 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 or events.**

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, …..

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. 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.

2.2 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.

Example

Table 1.1 Examples of Systems and Components

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	Origination; 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

2.3 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.

2.4 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.

3. 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

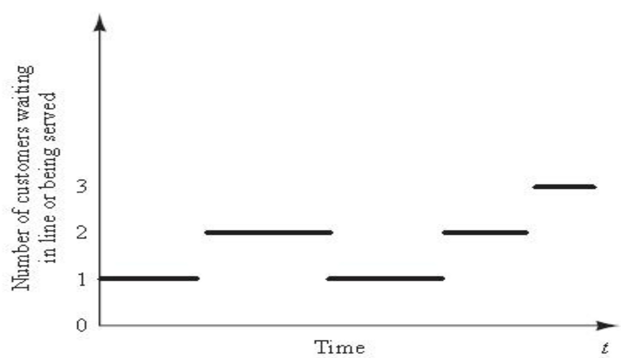


Figure 1.1 Discrete-system state variable.

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.

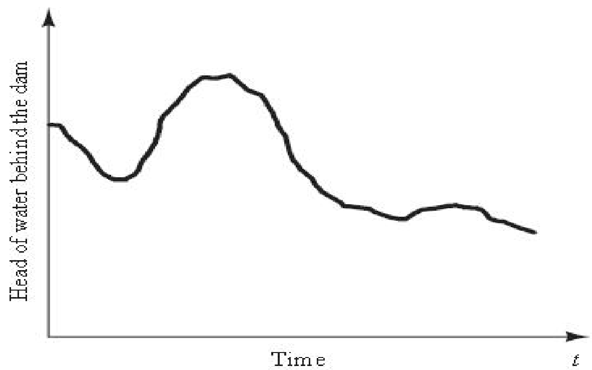


Figure 1.2 Continuous-system state variable.

4. 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.

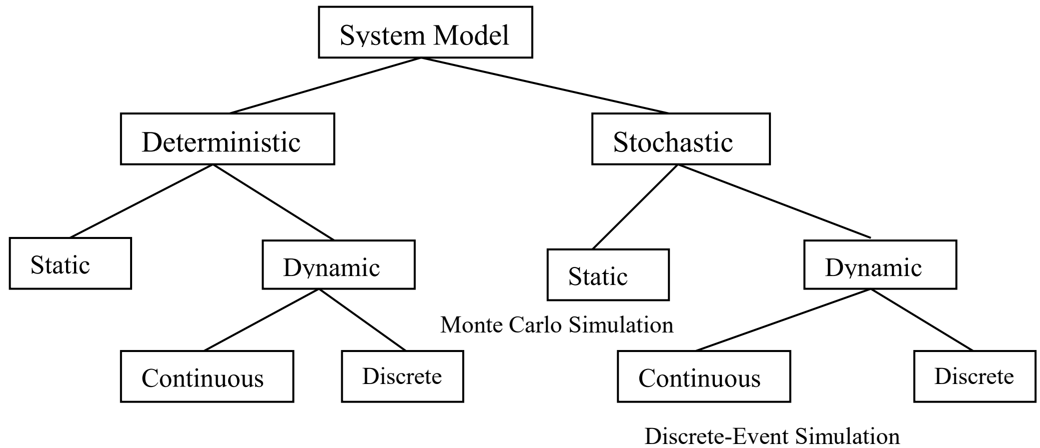
Supplying data provides value contained an attribute and define relationships involved in the activities.

Types of Model

The various types of models are shown in figure below.

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

The chart to represent different model in a hierarchy is as shown below



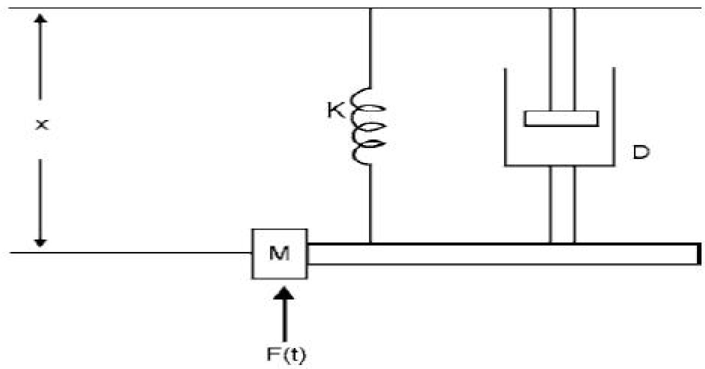
Physical model

These models are based on some analogy between mechanical and electrical system The system attributes are represented by physical measures such as voltage. The system activities are represented by physical laws.

Physical models are of two types, static and dynamic. Static physical model is a scaled down model of a system which does not change with time. An architect before constructing a building makes a scaled down model of the building, which reflects all it rooms, outer design and other important features. This is an example of static physical model. Similarly for conducting trials in water, we make small water tanks, which are replica of sea, and fire small scaled down shells in them. This tank can be treated as a static physical model of ocean. Dynamic physical models are ones which change with time or which are function of time. In wind tunnel, small aircraft models (static models) are kept and air is blown over them with different velocities and pressure profiles are measured with the help of transducers embedded in the model. Here wind velocity changes with time and is an example of dynamic physical model.

Let us take an example of hanging wheel of a stationary truck and analyze its motion under various forces. Consider a wheel of mass M, suspended in vertical direction, a force $F(t)$, which varies with time, is acting on it. Mass is connected with a spring of stiffness K, and a piston with damping factor D. When force $F(t)$, is applied, mass M oscillates under the action of these three forces.

This model can be used to study the oscillations in a motor wheel. Figure below shows such a system. This is a discrete physical static model. Discrete in a sense, that one can give discrete values F and observe the oscillations of wheel with some measuring equipment. When force is applied on it, which is a function of time, this discrete physical static model becomes dynamic model. Parameters K and D can also be adjusted in order to get controlled oscillations of the wheel. This type of system is called spring-mass system or wheel suspension. Load on the beams of a building can be studied by the combination of spring-mass system.



Mathematical Model

It uses symbolic notation and mathematical equation to represent system. The system attributes are represented by variables and the activities are represented by mathematical function.

Example: f(x) = mx+c is a mathematical model of a line.

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

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.

Principles used in Modeling

Guidelines 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:

1. **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.

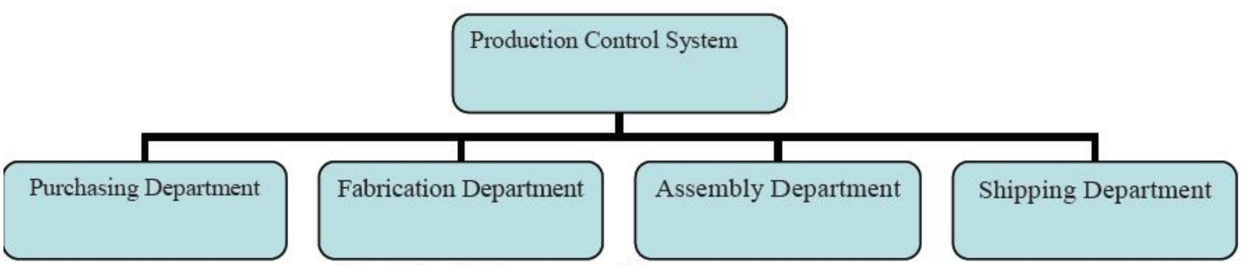


Fig: Block diagram of factory system

2. **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.

3. **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.

4. **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.

Distributed lag model

Models that have the property of changing only at fixed interval of time and based on current values of variables on other current values of variables are called distributed lag model.

In economic studies some economic data are collected over uniform time interval such as a month or year.

This model consists of linear algebraic equations that represent continuous system but data are available at fixed points in time.

For example: Mathematical model of national economy

Let

C=consumption

I=investment

T=Taxes

G=government expenditures

Y=national income

Then

$C=20+0.7(Y-T)$

$I=2+0.1Y$

$T=0.2Y$

$Y=C+I+G$

All the equation are expressed in billions of rupees. This is static model and can be made dynamic by lagging all the variables as follows

$C=20+0.7(Y-1-T-1)$

$I=2+0.1Y-1$

$T=0.2Y-1$

$Y=C-1+I-1+G-1$

Any variable that can be expressed in the form of its current value and one or more previous value is called lagging variable. And hence this model is given the name distributed lag model. the variable in a previous interval is denoted by attaching –n suffix to the variable. Where -n indicate the nth interval.

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.

Use of Differential and Partial differential equations in Modeling

A **partial differential equation** (**PDE**) is a mathematical equation that involves two or more independent variables, an unknown function (dependent on those variables), and partial derivatives of the unknown function with respect to the independent variables. The *order* of a *partial differential equation* is the order of the highest derivative involved. A *solution to a partial differential equation* is a function that solves the equation.

Partial differential equations are used to mathematically formulate, and thus aid the solution of, physical and other problems involving functions of several variables, such as the propagation of heat or sound, fluid flow, elasticity, electrostatics, electrodynamics, etc.

For the design of the approximation model, two demands should be taken into account. Firstly, the characteristic system parameters, i.e., the throughput and the flow time, should be accurately described in both transient and steady state. Secondly, the approximation model should be suitable for the design of a continuous controller, which implies that the model must be continuous and computationally feasible. None of the available approximation models for manufacturing systems, however, complies with all these demands, and therefore a new class of models, namely PDE-models (PDE: partial differential equation), is considered. These models are continuous and computationally feasible, but their description of a manufacturing system's behavior has not been validated so far. Therefore, the suitability of PDE-models in simulation of manufacturing systems is investigated. A second aim of this research project is to investigate the possibilities of such a PDE-model in the control of a manufacturing system, when using the framework described above.

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?

1. Simulation should not be used when the problem can be solved using common sense.

2. Simulation should not be used if the problem can be solved analytically.

3. Simulation should not be used if it is easier to perform direct experiments.etc

4. Simulation should be used when the problem cannot be solved using common sense.

5. Simulation should not be used, if the costs exceeds savings.

6. Simulation should not be performed, if the resources or time are not available.

7. if no data is available, not even estimate simulation is not advised.

8. If there is not enough time or the persons are not available, simulation is not appropriate.

9. If managers have unreasonable expectation say, too much soon – or the power of simulation is over estimated, simulation may not be appropriate.

10. If system behavior is too complex or cannot be defined, simulation is not appropriate.

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 fabs.
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.

Steps on simulation Study

1. Problem formulation

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

2. 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 kind 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

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

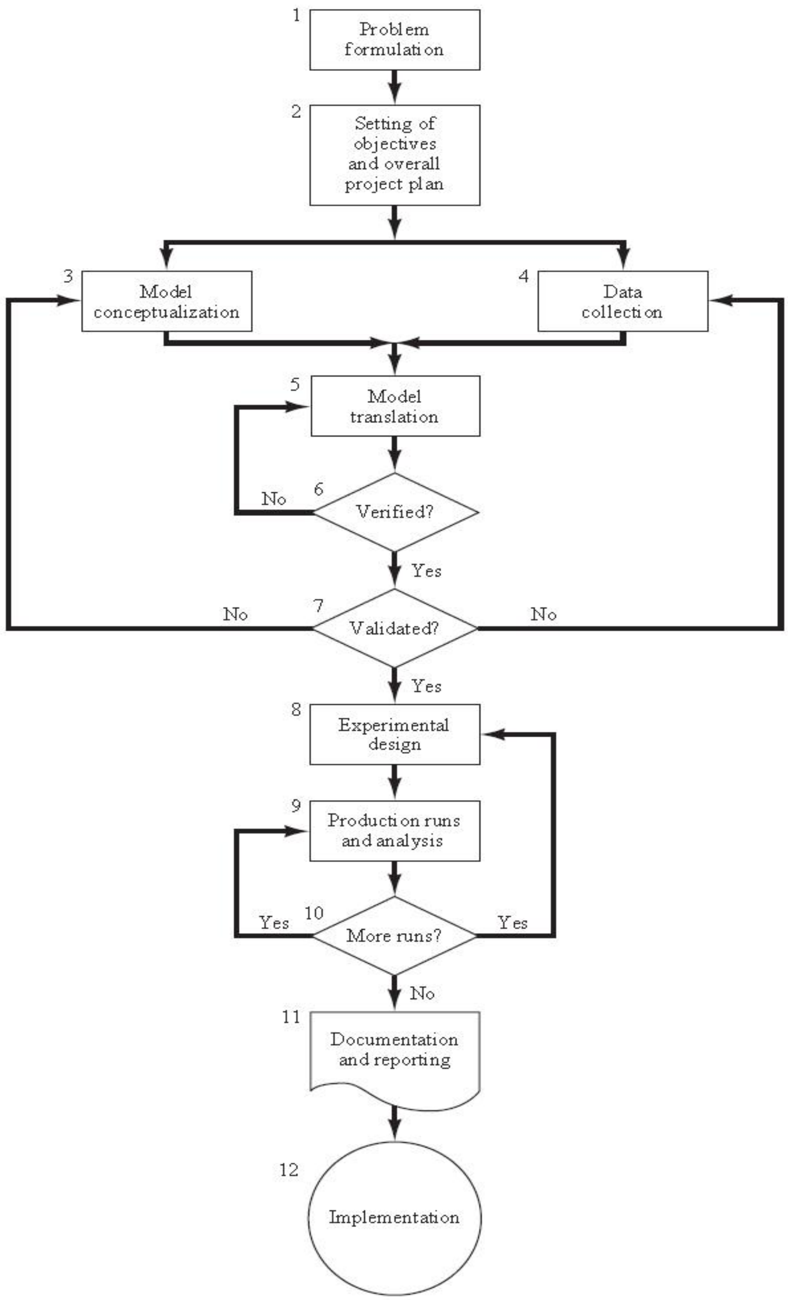


Figure 1.3 Steps in a simulation study.

completion.

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 replace physical device with virtual device are.

(Note : please read about the mathematical and physical model form the Gorden book with example of wheel suspension and electric capacity)

Question: Differentiate between dynamic physical models and static physical models with example.