lecture 1.1

INTRODUCTION

1. Introduction to Simulation and Modeling

Simulation is the process of design model of a real system to understanding the behavior of the system and/or evaluating various strategies for the operation of the system. Whether done by hand or on a computer, simulation involves the generation of an artificial history of a system, and the observation of that artificial history to draw inferences concerning the operating characteristics of the real system.

The behavior of a system as it evolves over time is studied by developing a simulation model. This model usually takes the form of a set of assumptions concerning the operation of the system. These assumptions are expressed in mathematical, logical, and symbolic relationships between the entities, or objects of interest, of the system. Once developed and validated, a model can be used to investigate a wide variety of "*what-if*" questions about the real- world system. Potential changes to the system can first be simulated in order to predict their impact on system performance. Simulation can also be used to study systems in the design stage, before such systems are built. Thus, simulation modeling can be used both as an analysis tool for predicting the effect of changes to existing systems, and as a design tool to predict the performance of new systems under varying sets of circumstances.

In some instances, a model can be developed which is simple enough to be "solved" by mathematical methods. Such solutions may be found by the use of differential calculus, probability theory, algebraic methods, or other math- ematical techniques. The solution usually consists of one or more numerical parameters which are called measures of performance of the system. How- ever, many real-world systems are so complex that models of these systems are virtually impossible to solve mathematically. In these instances, numerical, computer-based simulation can be used to imitate the behavior of the system over time. From the simulation, data are collected as if a real system were being observed. This simulation-generated data is used to estimate the measures of performance of the system.

This book provides an introductory treatment of the concepts and methods of one form of simulation modeling discrete-event simulation modeling. The first chapter initially discusses when to use simulation, its advantages and disadvantages, and actual areas of application. Then the concepts of system and model are explored. Finally, an outline is given of the steps in building and using a simulation model of a system.

What is Model?

- Is an abstract representation (real) system , object, that captures the essential characteristics or properties of the system or object . Model used to understand this system
- Then we can say: Model consider a Construct conceptual of the framework that describes system.
- Often requires making simplifying assumptions about how the system works

Examples:

- Model airplane, molecular model, performance for any model

Remarks :

- Modeling is an essential tool in computer system
- Model is both “art” and “science”
  - Art when minimize the parameter’s model
  - Science because using statics, mathematic, programing
- Model reality check: George Box , 1979 :

“All models are wrong, some models are useful”

- Models are wrong because not all parameter consider in model
- Models are useful when provide the performance of the system behavior.
- Models are especially valuable when are simple, elegant and fast

Modeling is a way of looking at the world

- Any system can have multiple models
- Models simplified thing
- Using the appropriate model allows us to make decisions, even on the system when the situation is complex or resources are limited

- We are always using models

Goals of Modeling and simulation

- A model can be used to investigate a wide verity of " What if " questions about real world system.
- Potential changes to the system can be simulated and predicate their impact on the system.
- Find adequate parameters before implementation.
- So simulation can be used as
  - Analysis tool for predicating the effect of changes.
  - Design tool to predicate the performance of new system.
- It is better to do simulation before implementation.

How a model can be developed?

- **A Mathematical Methods:**
  - Uses symbolic notations and equations to represent a system
  - Probability theory ,algebraic methods.…,
  - Their results are accurate.
  - They have a few number of parameters
  - It is impossible for complex systems.
- **A Numerical Computer-based simulation**
  - It is simple
  - It is useful for complex system.

1.1 When is Simulation the 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. Circumstances under which simulation is the appropriate tool to use have been discussed by many authors, from Naylor et al. [1966] to Banks et al. [1996]. 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 as a pedagogical device to reinforce analytic solution methodologies.
6. Simulation can be used to experiment with new designs or policies prior to implementation, so as to prepare for what may happen.
7. Simulation can be used to verify analytic solutions.
8. By simulating different capabilities for a machine, requirements can be determined.
9. Simulation models designed for training allow learning without the cost and disruption of on-the-job learning.
10. Animation shows a system in simulated operation so that the plan can be visualized.
11. The modern system (factory, wafer fabrication plant, service organization, etc.) is so complex that the interactions can be treated only through simulation.

1.2 When Simulation Is Not Appropriate

This section is based on an article by Banks and Gibson [1997], who gave ten rules for determining when simulation is not appropriate. The first rule indicates that simulation should not be used when the problem can be solved using common sense. An example is given of an automobile-tag facility serving customers who arrive randomly at an average rate of 100/hour and are served at a mean rate of 12/hour. To determine the minimum number of servers needed, simulation is not necessary. Just compute 100/12 = 8.33, indicating that nine or more servers are needed.

The second rule says that simulation should not be used if the problem can be solved analytically. For example, under certain conditions, the average waiting time in the example above can be determined from curves that were developed by Hillier and Lieberman [1995].

The next rule says that simulation should not be used if it is easier to perform direct experiments. An example of a fast-food drive-in restaurant is given, where it was less expensive to have a person use a hand-held terminal and voice communication to determine the effect of adding another order station on customer waiting time.

The fourth rule says not to use simulation, if the costs exceed the savings. There are many steps in completing a simulation as discussed in Section 1.11, and these must be done thoroughly. If a simulation study costs $20,000 and the savings might be $10,000, simulation would not be appropriate.

Rules five and six indicate that simulation should not be performed if the resources or time are not available. If the simulation is estimated to cost $20,000 and only $10,000 is available, the suggestion is not to venture into a simulation study. Similarly, if a decision in needed is two weeks and a simulation will take a month, the simulation study is not advised.

Simulation takes data, sometimes lots of data. If no data is available, not even estimates, simulation is not advised.

The next rule concerns the ability to verify and validate the model. If there is not enough time or the personnel are not available, simulation is not appropriate.

If managers have unreasonable expectations—say, too much too soon or the power of simulation is overestimated, simulation may not be appropriate.

Last, if system behavior is too complex or can't be defined, simulation is not appropriate. Human behavior is sometimes extremely complex to model.

1.3 Advantages and Disadvantages of Simulation

Simulation is intuitively appealing to a client because it mimics what happens in a real system or what is perceived for a system that is in the design stage. The output data from a simulation should directly correspond to the outputs that could be recorded from the real system. Additionally, it is possible to develop a simulation model of a system without dubious assumptions (such as the same statistical distribution for every random variable) of mathematically solvable models. For these, and other reasons, simulation is frequently the technique of choice in problem solving.

In contrast to optimization models, simulation models are "run" rather than solved. Given a particular set of input and model characteristics, the model is run and the simulated behavior is observed. This process of changing inputs and model characteristics results in a set of scenarios that are evaluated. A good solution, either in the analysis of an existing system or the design of a new system, is then recommended for implementation.

Simulation has many advantages, and even some disadvantages. These are listed by Pegden, Shannon, and Sadowski [1995]. The advantages are:

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

The disadvantages are:

1. Model building requires special training. It is an art that is learned over time and through experience. Furthermore, if two models are constructed by two competent individuals, they may have similarities, but it is highly unlikely that they will be the same.
2. Simulation results may be difficult to interpret. Since most simulation outputs are essentially random variables (they are usually based on ran- dom inputs), it may be hard to determine whether an observation is a result of system interrelationships or randomness.
3. Simulation modeling and analysis can be time consuming and expensive. Skimping on resources for modeling and analysis may result in a simula- tion model or analysis that is not sufficient for the task.
4. Simulation is used in some cases when an analytical solution is possible, or even preferable, as discussed in Section 1.2. This might be particularly true in the simulation of some waiting lines where closed-form queueing models are available.

In defense of simulation, these four disadvantages, respectively, can be offset as follows:

1. Vendors of simulation software have been actively developing packages that contain models that need only input data for their operation. Such models have the generic tag "simulators" or "templates."
2. Many simulation software vendors have developed output analysis capa- bilities within their packages for performing very thorough analysis.
3. Simulation can be performed faster today than yesterday, and even faster tomorrow. This is attributable to the advances in hardware that permit rapid running of scenarios. It is also attributable to the advances in many simulation packages. For example, some simulation software contains constructs for modeling material handling using transporters such as fork lift trucks, conveyors, automated guided vehicles, and others.
4. Closed-form models are not able to analyze most of the complex systems that are encountered in practice. In nearly eight years of consulting prac- tice by one of the

authors, not one problem was encountered that could have been solved by a closed-form solution.

1.4 Areas of Application

The applications of simulation are vast. The Winter Simulation Conference (WSC) is an excellent way to learn more about the latest in simulation ap- plications and theory. There are also numerous tutorials at both the begin- ning and advanced levels. WSC is sponsored by six technical societies and the National Institute of Standards and Technology (NIST). The technical soci- eties are American Statistical Association (ASA), Association for Computing Machinery/Special Interest Group on Simulation (ACM/SIGSIM), Institute of Electrical and Electronics Engineers: Computer Society (IEEE/CS), Insti- tute of Electrical and Electronics Engineers: Systems, Man and Cybernetics Society (IEEE/SMCS), Institute of Industrial Engineers (IIE), Institute for Operations Research and the Management Sciences: College on Simulation (INFORMS/CS), and The Society for Computer Simulation (SCS). Note that IEEE is represented by two bodies. Information about the upcoming WSC can be obtained from *www.wintersim.org*.

Some of the areas of application at a recent WSC, with the subject matter within those areas, is listed below:

1. **Manufacturing Applications**

Analysis of electronics assembly operations

Design and evaluation of a selective assembly station for high-precision scroll compressor shells

Comparison of dispatching rules for semiconductor manufacturing using large-facility models

Evaluation of cluster tool throughput for thin-film head production Determining optimal lot size for a semiconductor back-end factory Optimization of cycle time and utilization in semiconductor test manufacturing

Analysis of storage and retrieval strategies in a warehouse Investigation of dynamics in a service-oriented supply chain Model for an Army chemical munitions disposal facility

2. **Semiconductor Manufacturing**

Comparison of dispatching rules using large-facility models

The corrupting influence of variability

A new lot-release rule for wafer fabs

Assessment of potential gains in productivity due to proactive reticle man- agement

Comparison of a 200-mm and 300-mm X-ray lithography cell

Capacity planning with time constraints between operations

300-mm logistic system risk reduction

3. **Construction Engineering**

Construction of a dam embankment

Trenchless renewal of underground urban infrastructures Activity scheduling in a dynamic, multiproject setting Investigation of the structural steel erection process Special-purpose template for utility tunnel construction

4. **Military Applications**

Modeling leadership effects and recruit type in an Army recruiting station

Design and test of an intelligent controller for autonomous underwater vehicles

Modeling military requirements for nonwarfighting operations

Multitrajectory performance for varying scenario sizes

Using adaptive agents in U.S. Air Force pilot retention

5. **Logistics, Transportation, and Distribution Applications**

Evaluating the potential benefits of a rail-traffic planning algorithm

Evaluating strategies to improve railroad performance

Parametric modeling in rail-capacity planning Analysis of passenger flows in an airport terminal Proactive flight-schedule evaluation

Logistics issues in autonomous food production systems for extended-duration space exploration

Sizing industrial rail-car fleets

Product distribution in the newspaper industry

Design of a toll plaza

Choosing between rental-car locations

Quick-response replenishment

6. **Business Process Simulation**

Impact of connection bank redesign on airport gate assignment

Product development program planning Reconciliation of business and systems modeling

Personnel forecasting and strategic workforce planning

7. **Human Systems**

Modeling human performance in complex systems

Studying the human element in air traffic control

- **Simulation Examples**

— Hair Salon

— Two stylists (one fast, one slow)

— Limited size waiting room (N chairs)

— Customers arrive at random times (no appts)

— Customers are impatient (don't like waiting long)

- **<u>Steps of Model Building</u>**

1. Define an achievement goal
2. Put together a complete mix of skills on the team
3. Involve the end-user
4. Choose the appropriate simulation tools
5. Model the appropriate level(s) of detail
6. Start early to collect the necessary input data
7. Provide adequate and on-going documentation
8. Develop a plan for adequate model verification

   (Did we get the "right answers ?")

8. Develop a plan for model validation

   (Did we ask the "right questions ?")

9. Develop a plan for statistical output analysis

- **<u>Define an achievable goal</u>**

1. "To model Design…"

2. To model the…in order to select/determine feasibility/…is a goal.
3. Goal selection is not cast in concrete
4. Goals change with increasing insight

<u>- Put together a complete mix of skills on the team</u>

-Knowledge of the system under investigation

-System analyst skills (model formulation)

-Model building skills (model Programming)

-Data collection skills

-Statistical skills (input data representation)

-More statistical skills (output data analysis)

-Even more statistical skills (design of experiments)

-Management skills (to get everyone pulling in the same direction)

- **<u>Involve the end-user</u>**

-Modeling is a selling job!

-Does anyone believe the results?

-Will anyone put the results into action?

-The End-user (your customer) can (and must) do all of the above BUT, first he must be convinced!

-He must believe it is HIS Model!

<u>- The appropriate simulation tools</u>

Assuming Simulation is the appropriate means, three alternatives exist:

1. Build Model in a General Purpose Language (high level language)
2. Build Model in a General Simulation Language (Ansys in Engineering or human body)
3. Use a Special Purpose Simulation Package (Simulink with matlab)

- Languages used for simulation

FORTRAN

– Probably more models than any other language.

PASCAL

- Not as universal as FORTRAN

MODULA

- Many improvements over PASCAL

ADA

- Department of Defense attempt at standardization

C, C++

- Object-oriented programming language

Lecture 1.2

1.5 Systems

- Systems :is defined as a group of objects that are joined together in some regular interaction or interdependence towards the accomplishment of some purpose.

- System is a collection of entities (people, parts, messages, machines, servers, …) that act and interact together toward some end (to satisfy purpose if the system) (Schmidt and Taylor, 1970)

- Example:

1- system of bank, hospital, university,------etc

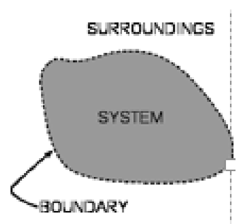
2- A production system manufacturing automobiles .Machines ,components parts and workers operate jointly along assembly lines to produce vehicles

3- A computer system : CPU , memory, disk, bus, NIC

1.5.1 System Environment

A system is affected by changes that occur outside system boundaries. Such changes are said to occur in the *system environment*

Input and output (i/o) variable affected the system



Ex: Hair salon (arrival customers)

- Example :*Bank System (arrival customers)*
- Arrival customers are even affected the system of bank
- There is a limit on the maximum interest ratethat can be paid affected on bank system
- study of the effect of monetary laws on the banking industry and the setting of the limit rate would be an activity of the bank system

To model a system, it is necessary to understand the concept of a system and the system boundary. A system is defined as a group of objects that are joined together in some regular interaction or interdependence toward the accom- plishment of some purpose. An example is a production system manufacturing automobiles. The machines, component parts, and workers operate jointly along an assembly line to produce a high-quality vehicle.

A system is often affected by changes occurring outside the system. Such changes are said to occur in the system environment [Gordon, 1978]. In model- ing 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.

In the case of the factory system, for example, the factors controlling the arrival of orders may be considered to be outside the influence of the factory and therefore part of the environment. However, if the effect of supply on demand is to be considered, there will be a relationship between factory output and arrival of orders, and this relationship must be considered an activity of the system. Similarly, in the case of a bank system, there may be a limit on the maximum interest rate that can be paid. For the study of a single bank, this would be regarded as a constraint imposed by the environment. In a study of the effects of monetary laws on the banking industry, however, the setting of the limit would be an activity of the system. [Gordon, 1978]

State of a system:

Collection of variables and their values necessary to describe the system at that time

- Might depend on desired objectives, output performance measures
- Bank model:Could include number of busy tellers, time of arrival of each customer , etc.

1.6 Components of a System

In order to understand and analyze a system, a number of terms need to be defined. An entity is an object of interest in the system. An attribute is a property of an entity. An activity represents a time period of specified length. If a bank is being studied, customers might be one of the entities, the balance in their checking accounts might be an attribute, and making deposits might be an activity.

The collection of entities that compose a system for one study might be only a subset of the overall system for another study [Law and Kelton, 2000]. For example, if the bank mentioned above is being studied to determine the number of tellers needed to provide for paying and receiving, the system can be defined as that portion of the bank consisting of the regular tellers and the customers waiting in line. If the purpose of the study is expanded to determine the number of special tellers needed (to prepare cashier's checks, to sell traveler's checks, etc.), the definition of the system must be expanded.

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. An event is defined as an instantaneous occurrence that may change the state of the system. The term endogenous is used to describe activities and events occurring within a system, and the term exogenous is used to describe activities and events in the environment that affect the system. In the bank study, the arrival of a customer is an exogenous event, and the completion of service of a customer is an endogenous event. Table 1.1 lists examples of entities, attributes, activities, events, and state variables for several systems. Only a partial listing of the system components is shown. A complete list cannot be developed unless the purpose of the study is known. Depending on the purpose, various aspects of the system will be of interest, and then the listing of components can be completed.

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

Then we can write the component of the system as:

1- Entity

-An object of interest in the system. Such that CPU in computer system , Machines in factory,……….

2- Attribute

The property of an entity. Such that speed, capacity, failure rate,……………

3- Activity

A time period of specified length, even which entity can do

4-State

A collection of variables that describe the system in any time:

status of machine(busy ,idle ,down).

5-Event

A instantaneous (represent)occurrence that might change the state of the system :

Ex: customer come, customer go, packets come to server to handle, machine idle…….

6-Endogenous

-Activities and events occurring with the system

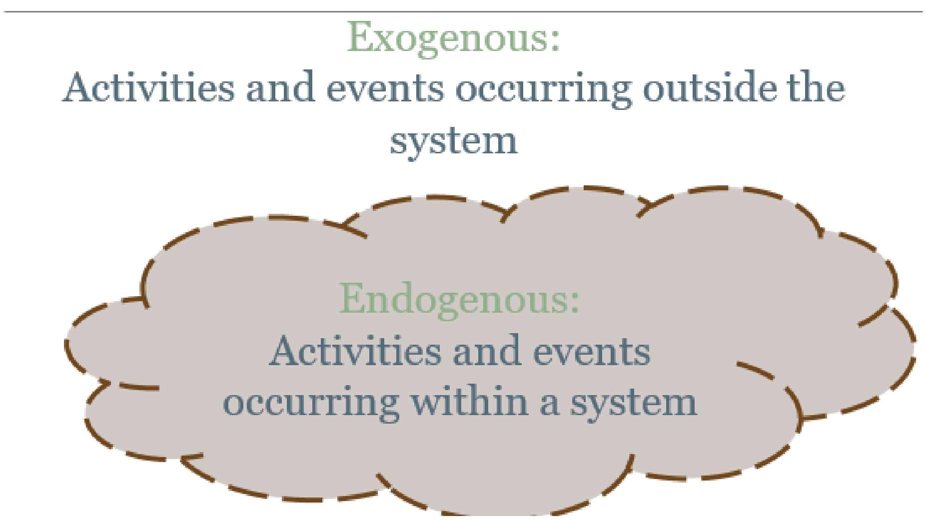
-Ex: The customer deposited and spent money in the bank

7-Exogenous

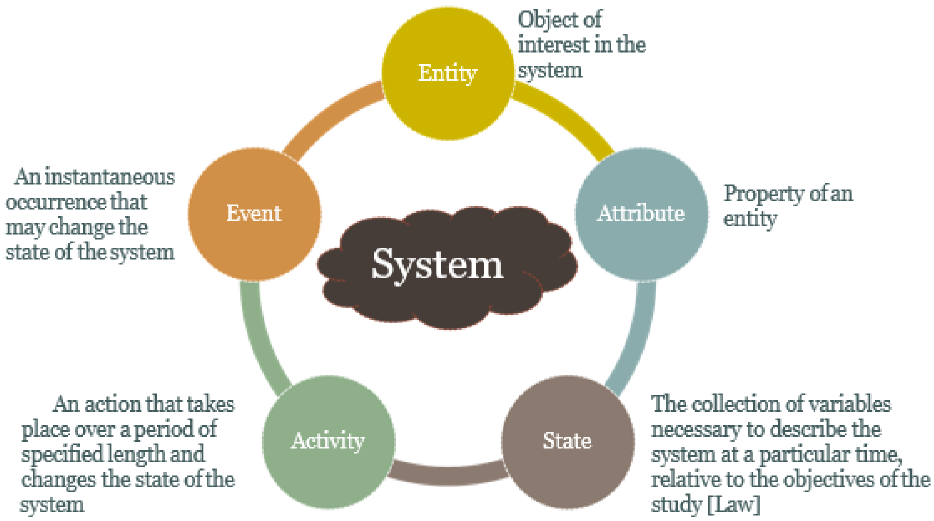
-Activities and events occurring with the environment

-Ex: customer in bank waited and go

Next figure show the exogenous and Endogenous



We can illustrate the system compoment in the following figure.



1.7 Types of Systems

1.7.1 Discrete Systems

A discrete system State variables of the system change only at discrete/separated set of points in time

Example: Bank Number of customers changes only when customer arrives or departs

Example: Restaurant

Systems can be categorized as discrete or continuous. “Few systems in practice are wholly discrete or continuous, but since one type of change predominates for most systems, it will usually be possible to classify a system as being either discrete or continuous” [Law and Kelton, 2000]. A discrete system is one in which the state variable(s) change only at a discrete set of points in time. The bank is an example of a discrete system since the state variable, the number of customers in the bank, changes only when a customer arrives or when the service provided a customer is completed. Figure 1.1 shows how the number of customers changes only at discrete points in time.

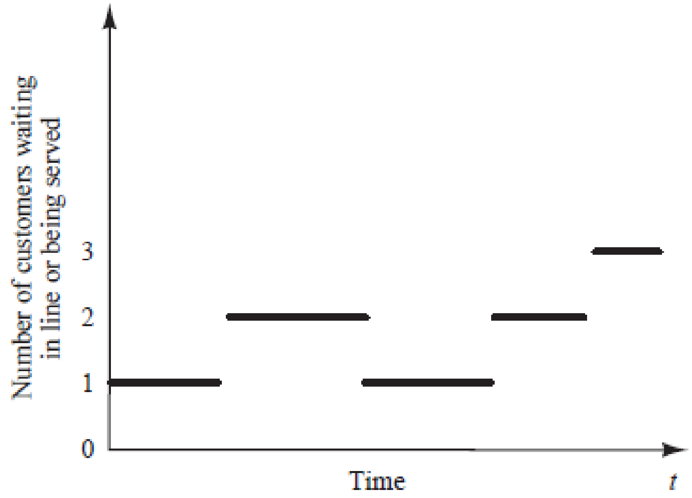
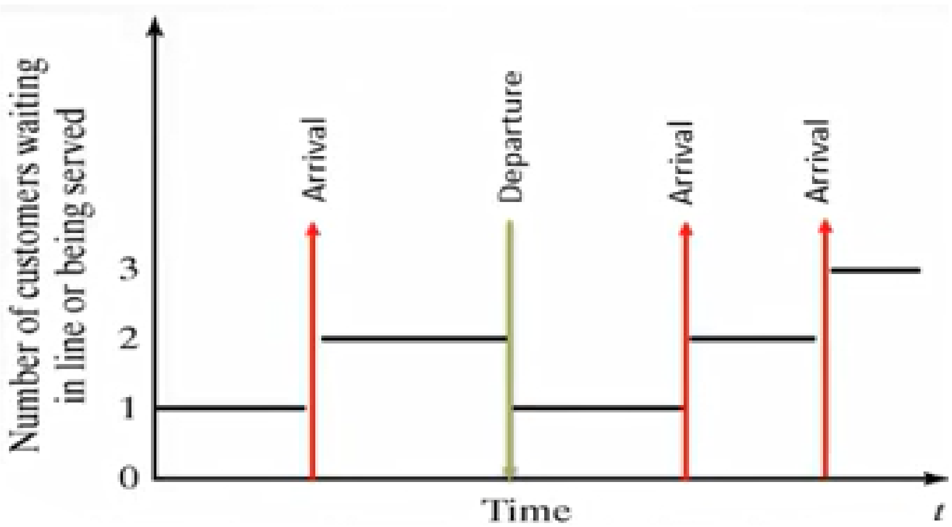


Figure 1.1 Discrete-system state variable.

A simulation model in which system state evolves a discrete sequence of events in time

- System state changes only when an event occurs
- System state does not change between the events



1.7.2 **Continuous Systems**

Continuous system State variables of the change continuously over the time

Example :head of water behind the dam .

Example :Airplane flight

Position and velocity are continuously changing with respect to time

A continuous system is one in which the state variable(s) change continu- ously over time. An example is the head of water behind a dam. During and for some time after a rain storm, water flows into the lake behind the dam. Water is drawn from the dam for flood control and to make electricity. Evaporation also decreases the water level. Figure 1.2 shows how the state variable, head of water behind the dam, changes for this continuous system.

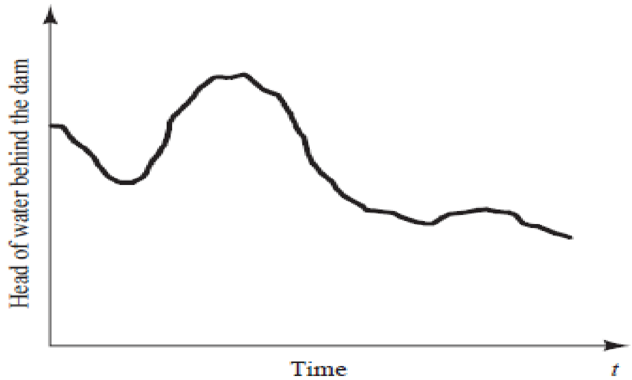
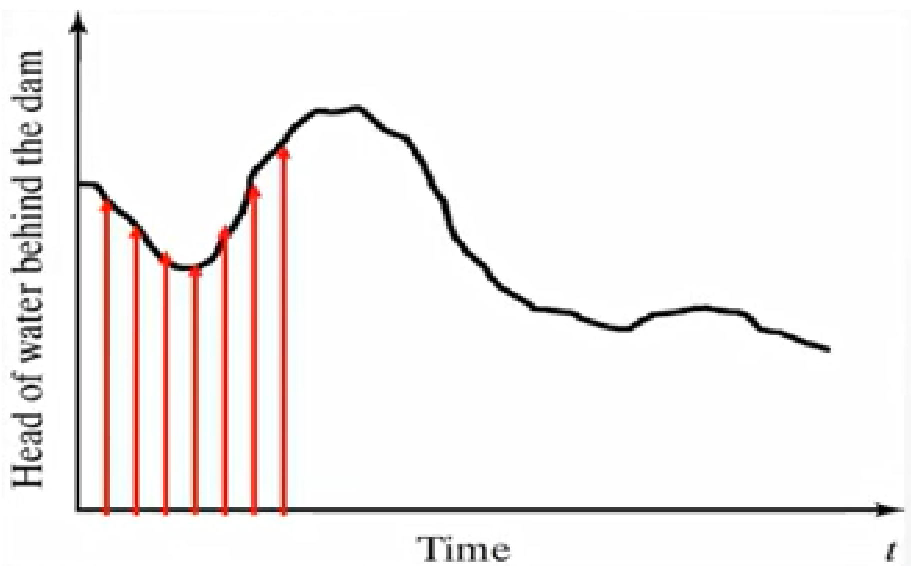


Figure 1.2 Continuous-system state variable.

A system model in which system state evolves continuously over time

- Time is divided to small time slices
- System state changes in every time slice



1.8 Model of a System

Sometimes it is of interest to study a system to understand the relationships between its components or to predict how the system will operate under a new policy. Sometimes it is possible to experiment with the system itself, but, not always. A new system may not yet exist; it may be only in hypothetical form or at the design stage. Even if the system exists, it may be impractical to experiment with it. For example, it may not be wise or possible to double the unemployment rate to determine the effect of employment on inflation. In the case of a bank, reducing the numbers of tellers to study the effect on the length of waiting lines may infuriate the customers so greatly that they move their accounts to a competitor. Consequently, studies of systems are often accomplished with a model of a system.

We had a consulting job for the simulation of a redesigned port in western Australia. At $200 million for a loading/unloading berth, it's not advisable to invest that amount only to find that the berth is inadequate for the task.

A model is defined as a representation of a system for the purpose of studying the system. For most studies, it is necessary to consider only those as- pects of the system that affect the problem under investigation. These aspects are represented in a model of the system, and the model, by definition, is a sim- plification of the system. On the other hand, the model should be sufficiently detailed to permit valid conclusions to be drawn about the real system. Differ- ent models of the same system may be required as the purpose of investigation changes.

Just as the components of a system were entities, attributes, and activities, models are represented similarly. However, the model contains only those components that are relevant to the study. The components of a model are discussed more extensively in Chapter 3.

Why are Models Used?

- It is not possible to experiment with the actual system without design Models ,e.g :. the experiment is destructive without model
- The system might not exist ,i.e .the system is in the design stage

Example :system of Bank without design model

- Studying of reducing the number of tellers that effect on the length of waiting lines customers may caused annoy the customers such that they will be move their accounts to a competitor (anther bank)

- Because A model is a representation of a system for the purpose of studying that system

- It is only necessary to consider those aspects of the system that affect the problem under investigation (models determine the problem in the system witch can be investigate the solution)

- The model is a simplified representation of the system

- The model should be sufficiently detailed to permit or provide me valid conclusions about the actual system

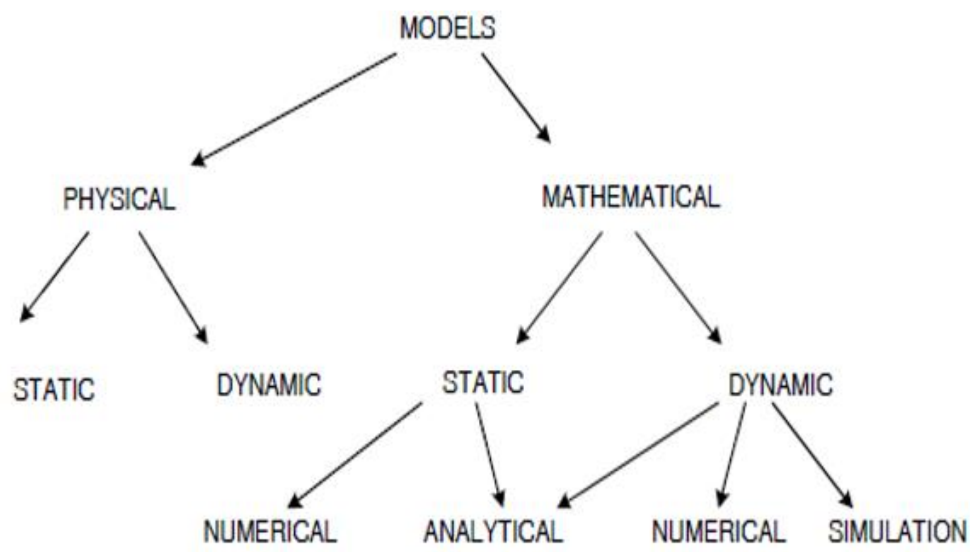
- Different models of the same system may be required as the purpose of the investigation changes

- By using model can remove Unnecessary details data

1.9 Types of Models

Models can be classified as being mathematical or physical. A mathematical model uses symbolic notation and mathematical equations to represent a system. A simulation model is a particular type of mathematical model of a system.

Next figure show types of Models

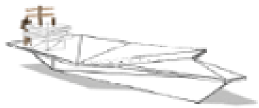
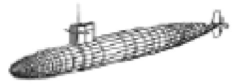
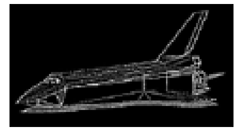


Physical Model is a larger or smaller version of an object.

The building of Physical Model is very expensive and has a size of space.

- Example :enlargement of an atom or a scaled (small) version of the solar system

Such building : Ship - space shuttle - submarine

—**Physical Model** is divide into static which not change with time such that building airplane, ship, high house and dynamic which change with time such that Internal combustion machine (have random variable or random number) .

— **A Mathematical Model** utilizes symbolic notations and equations to represent a system

A Mathematical Model consists of :

1- component

2-variables

3-parameters

4- functional relations

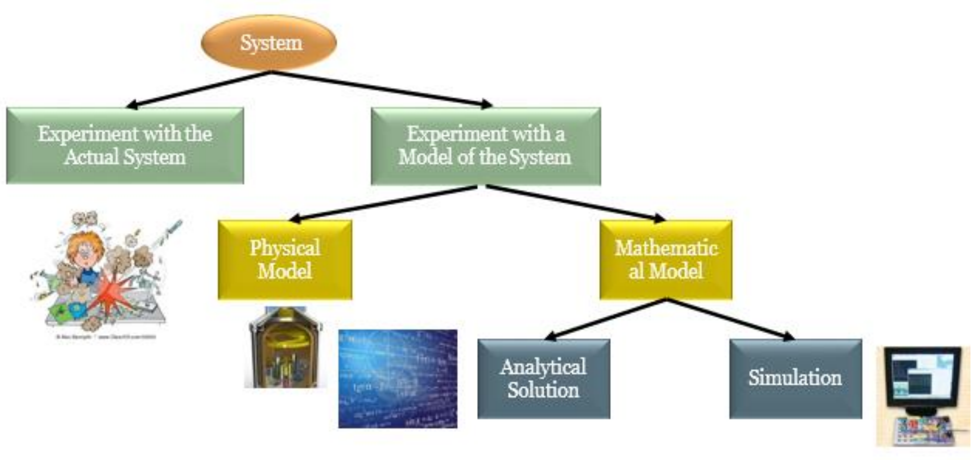
- Example: current and voltage equations are mathematical models of an electric circuit

Simulation models may be further classified as being static or dynamic, deterministic or stochastic, and discrete or continuous. A static simulation model, sometimes called a Monte Carlo simulation, represents a system at a particular point in time. Dynamic simulation models represent systems as they change over time. The simulation of a bank from 9:00 A.M. to 4:00 P.M. is an example of a dynamic simulation.

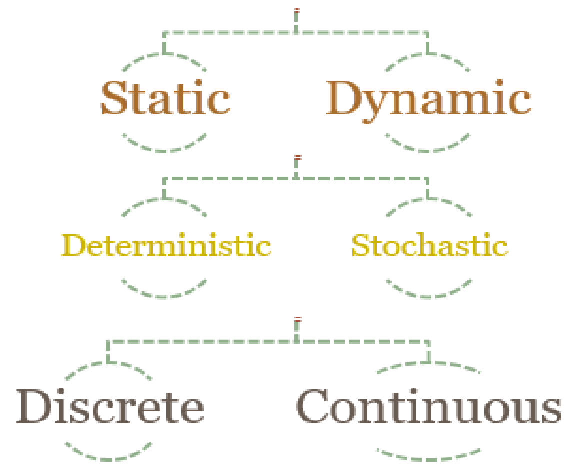
Simulation models that contain no random variables are classified as deterministic. Deterministic models have a known set of inputs which will result in a unique set of outputs. Deterministic arrivals would occur at a dentist's office if all patients arrived at the scheduled appointment time. A stochastic simulation model has one or more random variables as inputs. Random inputs lead to random outputs. Since the outputs are random, they can be considered only as estimates of the true characteristics of a model. The simulation of a bank would usually involve random interarrival times and random service times. Thus, in a stochastic simulation, the output measures the average number of people waiting, the average waiting time of a customer must be treated as statistical estimates of the true characteristics of the system.

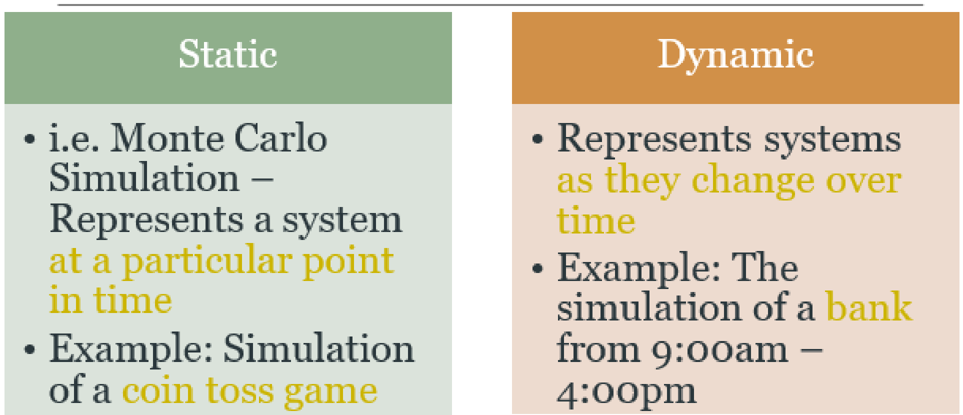
Discrete and continuous systems were defined in Section 1.6. Discrete and continuous models are defined in an analogous manner. However, a discrete simulation model is not always used to model a discrete system, nor is a continuous simulation model always used to model a continuous system. Tanks and pipes are modeled discretely by some software vendors, even though we know that fluid flow is continuous. In addition, simulation models may be mixed, both discrete and continuous. The choice of whether to use a discrete or continuous (or both discrete and continuous) simulation model is a func- tion of the characteristics of the system and the objective of the study. Thus, a communication channel could be modeled discretely if the characteristics and movement of each message were deemed important. Conversely, if the flow of messages in aggregate over the channel were of importance, modeling the system using continuous simulation could be more appropriate. The models considered in this text are discrete, dynamic, and stochastic.

The realtion between models and system can be illustrate by the following figure

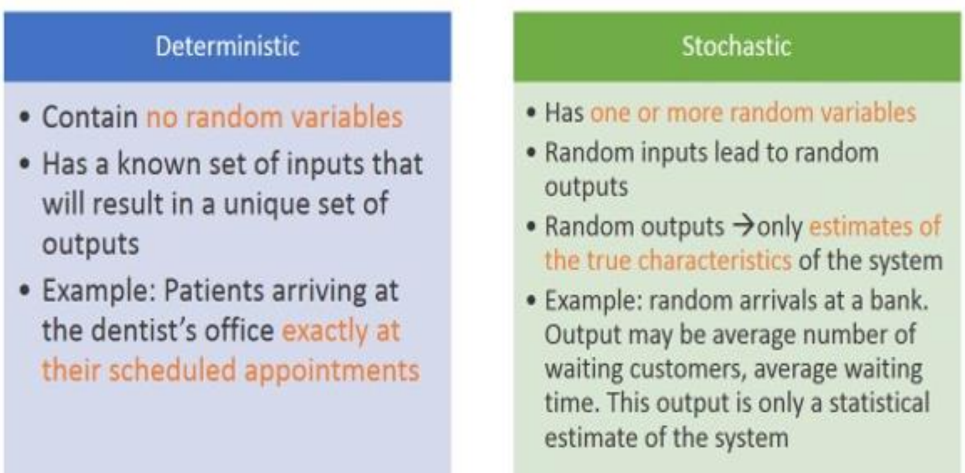


Classifications of Simulation Models





Deterministic and Stochastic Models

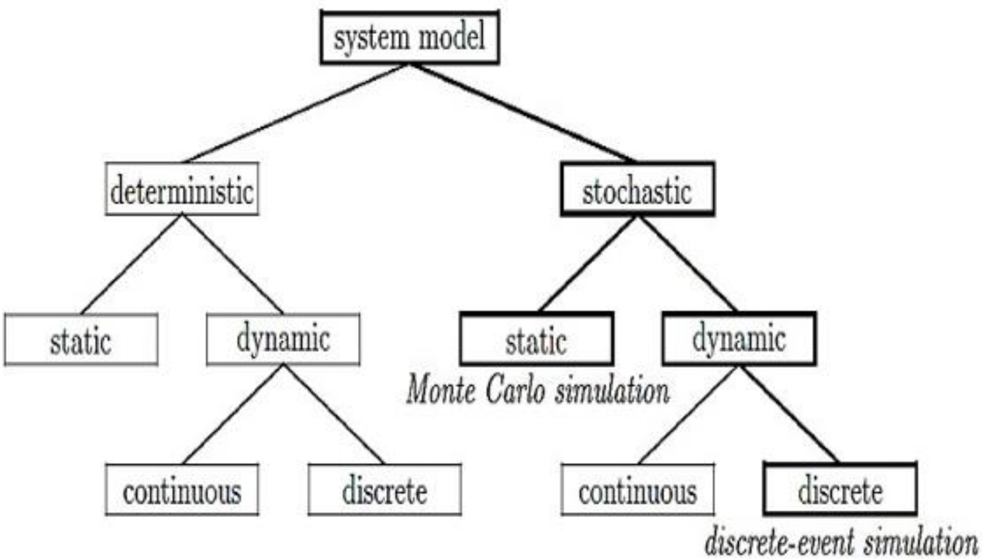


Discrete and Continuous Models

Discrete	Continuous
• Not always used to simulate a discrete system • Example: Tanks and pipes may be modeled discretely, even though the flow is continuous	• Not always used to simulate a continuous system

The choice of whether to use a discrete or continuous model depends on the characteristics of the system and the objectives of the study

Model Taxonomy



1.9 Model development steps

How to develop a model:

1. Determine the goals and objectives
2. Build a conceptual model (ex. Conceptual model for bank is queue, for liver is filtering)
3. Convert into a specification model
4. Convert into a computational model
5. Verify
6. Validate
7. Typically an iterative process

1.10 Discrete-Event System Simulation

This book is about discrete-event system simulation the modeling of systems in which the state variable changes only at a discrete set of points in time. The simulation models are analyzed by numerical rather than by analytical methods. Analytical methods employ the deductive reasoning of mathemat- ics to “solve” the model. For ex- ample, differential calculus can be used to determine the minimum-cost policy for some inventory models. Numerical methods employ computational procedures to “solve” mathematical models. In the case of simulation models, which employ numerical methods, models are “run” rather than solved; that is, an artificial history of the system is gen- er- ated based on the model assumptions, and observations are collected to be analyzed and to estimate the true system performance measures. Since real world simulation models are rather large, and since the amount of data stored and manipulated is so vast, the runs are usually conducted with the aid of a computer. However, much insight can be obtained by simulating small models manually.

In summary, this book is about discrete-event system simulation in which the models of interest are analyzed numerically, usually with the aid of a com- puter.

lecture 1.3

1.11 The Process of Simulation

1.12 Steps in a Simulation Study

Figure 1.3 shows a set of steps to guide a model builder in a thorough and sound simulation study. Similar figures and discussion of steps can be found in other sources [Shannon, 1975; Gordon, 1978; Law and Kelton, 2000]. The number beside each symbol in Figure 1.3 refers to the more detailed discussion in the text.

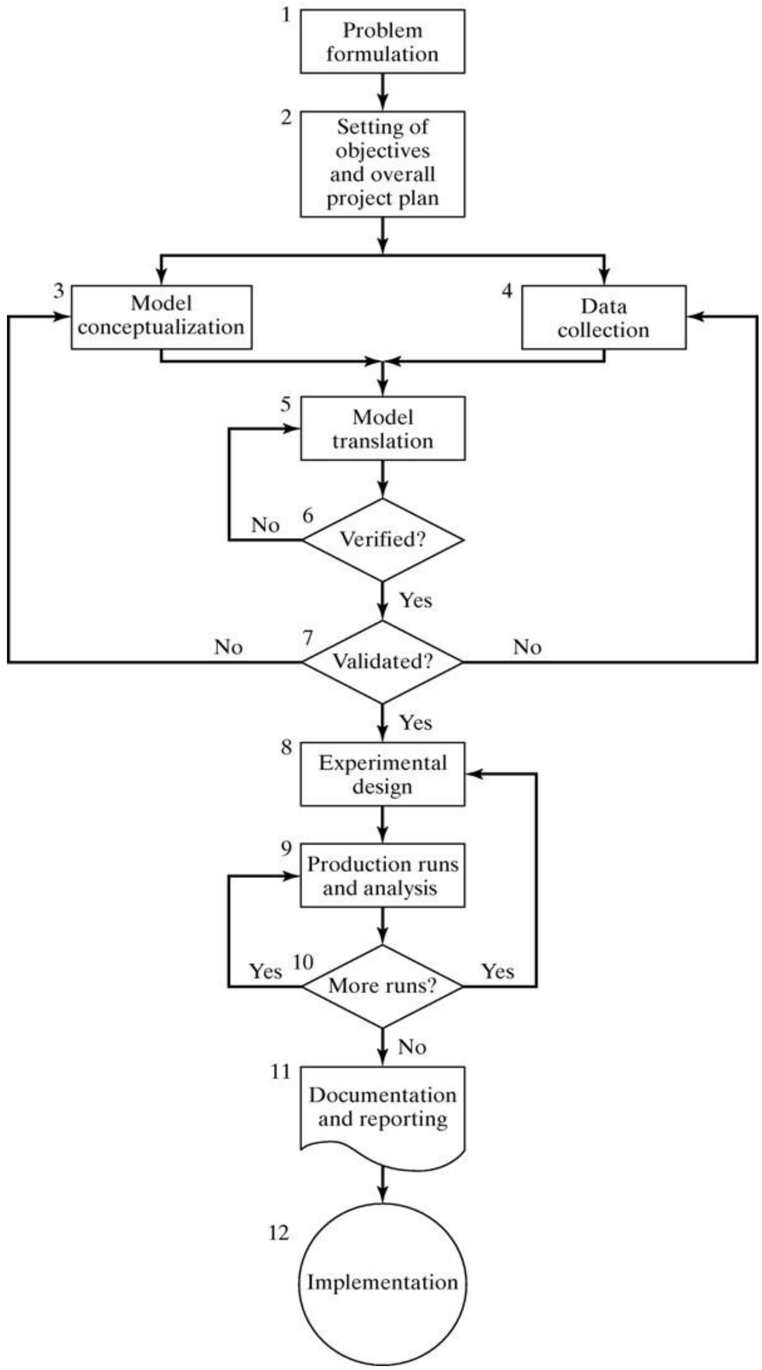


Figure 1.3 Steps in a simulation stud

The steps in a simulation study are as follows:

Problem formulation. Every study should begin with a statement of the prob- lem. If the statement is provided by the policy makers, or those that have the problem, the analyst must ensure that the problem being described is clearly understood. If a problem statement is being developed by the analyst, it is important that the policy makers understand

and agree with the formulation. Although not shown in Figure 1.3, there are occasions where the problem must be reformulated as the study progresses. In many instances, policy makers and analysts are aware that there is a problem long before the nature of the problem is known.

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 for the problem as formulated and objectives as stated. Assuming it is decided that simulation is appropriate, the overall project plan should include a statement of the alternative systems to be considered, and a method for evaluating the effectiveness of these alternatives. It should also include the plans for the study in terms of the number of people involved, the cost of the study, and the number of days required to accomplish each phase of the work with the anticipated results at the end of each stage.

Model conceptualization. The construction of a model of a system is proba- bly as much art as science. Pritsker [1998] provides a lengthy discussion of this step. “Although it is not possible to provide a set of instructions that will lead to building successful and appropriate models in every instance, there are some general guidelines that can be followed” [Morris, 1967]. The art of modeling is enhanced by an ability to abstract the essential features of a problem, to select and modify basic assumptions that characterize the system, and then 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. However, the model complexity need not exceed that required to accomplish the purposes for which the model is intended. Violation of this principle will only add to model-building and computer expenses. It is not necessary to have a one-to- one mapping between the model and the real system. Only the essence of the real system is needed.

It is advisable to involve the model user in model conceptualization. This will both enhance the quality of the resulting model and increase the confidence of the model user in the application of the model. (Chapter 2 describes a number of simulation models. Chapter 6 describes queueing models that can be solved analytically. However, only experience with real systems—versus textbook problems—can “teach” the art of model building.)

Data collection. There is a constant interplay between the construction of the model and the collection of the needed input data [Shannon, 1975]. As the complexity of the model changes, the required data elements may also change. Also, since data collection takes such a large portion of the total time required to perform a simulation, it is necessary to begin it as early as possible, usually together with the early stages of model building.

The objectives of the study dictate, in a large way, the kind of data to be collected. In the study of a bank, for example, if the desire is to learn about the length of waiting lines as the number of tellers change, the types of data needed would be the distributions of interarrival times (at different times of the day), the service-time distributions for the tellers, and historic distributions on the lengths of waiting lines under varying conditions. These last data will be used to validate the simulation model. (Chapter 9 discusses data collection and data analysis; Chapter 5 discusses statistical distributions which occur frequently in simulation modeling. See also an excellent discussion by Vincent [1998].)

Model translation. Since most real-world systems result in models that re- quire a great deal of information storage and computation, the model must be entered into a computer-recognizable format. We use the term “program,” even though it is possible to accomplish the desired result in many instances with little or no actual coding. The modeler must decide whether to program the model in a simulation language such as GPSS/H© (discussed in Chapter 4) or to use special-purpose simulation software. For manufacturing and material handling, Chapter 4 discusses Arena® , AutoMod© , CSIM, Extend© , Micro Saint, ProModel® , Dened/Quest® , Taylor Eneterprise Dynamics (ED), and Witness© . Simulation languages are powerful and flexible. However, if the problem is amenable to solution with the simulation software, the model de- velopment time is greatly reduced. Furthermore, most of the simulation soft- ware packages have added features that enhance their flexibility, although the amount of flexibility varies greatly.

Verified? Verification pertains to the computer program prepared for the sim- ulation model. Is the computer program performing properly? With complex models it is difficult, if not impossible, to translate a model successfully in its entirety without a good deal of debugging. If the input parameters and logical structure of the model are correctly represented in the computer, verification has been completed. For the most part, common sense is used in completing this step. (Chapter 10 discusses verification of simulation models, and Balci [1998] also discusses this topic extensively.)

Validated? Validation is the determination that a model is an accurate rep- resentation of the real system. Validation is usually achieved through the cal- ibration of the model, an iterative process of comparing the model to actual system behavior and using the discrepancies between the two, and the insights

gained, to improve the model. This process is repeated until model accuracy is judged acceptable. In the example of a bank mentioned above, data were collected concerning the length of waiting lines under current conditions. Does the simulation model replicate this system measure? This is one means of val- idation. (Chapter 10 discusses the validation of simulation models, and Balci [1998] also discusses this topic extensively.)

Experimental design. The alternatives that are to be simulated must be de- termined. Often, the decision concerning which alternatives to simulate may be a function of runs that have been completed and analyzed. For each system design that is simulated, decisions need to be made concerning the length of the initialization period, the length of simulation runs, and the number of replica- tions to be made of each run. (Chapter 11 and 12 discuss issues associated with the experimental design, and Kleijnen [1998] discusses this topic extensively.)

Production runs and analysis. Production runs, and their subsequent analy- sis, are used to estimate measures of performance for the system designs that are being simulated. [Chapters 11 and 12 discuss the analysis of simulation experiments, and Chapter 4 discusses software to aid in this step, including Au- toStat (in AutoMod), OptQuest (in several simulation softwares), SimRunner (in ProModel) and the Arena Output Analyzer.]

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

Documentation and reporting. There are two types of documentation: pro- gram and progress. Program documentation is necessary for numerous reasons. If the program is going to be used again by the same or different analysts, it may be necessary to understand how the program operates. This will build confi- dence in the program, so that model users and policy makers can make decisions based on the analysis. Also, if the program is to be modified by the same or a different analyst, this can be greatly facilitated by adequate documentation. One experience with an inadequately documented program is usually enough to convince an analyst of the necessity of this important step. Another reason for documenting a program is so that model users can change parameters at will in an effort to determine the relationships between input parameters and output measures of performance, or to determine the input parameters that "optimize" some output measure of performance.

Musselman [1998] discusses progress reports that provide the important, written history of a simulation project. Project reports give a chronology of work done and decisions made. This can prove to be of great value in keeping the project on course.

Musselman suggests frequent reports (monthly, at least) so that even those not involved in the day-to-day operation can keep abreast. The awareness of these others can usually enhance the successful completion of the project by surfacing misunderstandings early, when the problem can be solved easily. Musselman also suggests maintaining a project log providing a comprehensive record of accomplishments, change requests, key decisions, and other items of importance.

On the reporting side, Musselman suggests frequent deliverables. These may or may not be the results of major accomplishments. His maxim is that "it is better to work with many intermediate milestones than with one absolute deadline." Possibilities prior to the final report include a model specification, prototype demonstrations, animations, training results, intermediate analyses, program documentation, progress reports, and presentations. He suggests that these deliverables should be timed judiciously over the life of the project.

The result of all the analysis should be reported clearly and concisely in a final report. This will enable the model users (now, the decision makers) to review the final formulation, the alternative systems that were addressed, the criterion by which the alternatives were compared, the results of the ex- periments, and the recommended solution to the problem. Furthermore, if decisions have to be justified at a higher level, the final report should provide a vehicle of certification for the model user/decision maker and add to the credibility of the model and the model-building process.

Implementation. The success of the implementation phase depends on how well the previous eleven steps have been performed. It is also contingent upon how thoroughly the analyst has involved the ultimate model user during the entire simulation process. If the model user has been thoroughly involved and understands the nature of the model and its outputs, the likelihood of a vigor- ous implementation is enhanced [Pritsker, 1995]. Conversely, if the model and its underlying assumptions have not been properly communicated, implemen- tation will probably suffer, regardless of the simulation model's validity.

The simulation model-building process shown in Figure 1.3 can be broken down into four phases. The first phase, consisting of steps 1 (Problem Formula- tion) and 2 (Setting of Objective and Overall Design), is a period of discovery or orientation. The initial statement of the problem is usually quite "fuzzy," the initial objectives will usually have to be reset, and the original project plan will usually have to be fine-tuned. These recalibrations and clarifications may occur in this phase, or perhaps after or during another phase (i.e., the analyst may have to restart the process).

The second phase is related to model building and data collection and includes steps 3 (Model Conceptualization), 4 (Data Collection), 5 (Model Translation), 6 (Verification), and 7 (Validation). A continuing interplay is required among the steps. Exclusion of the model user during this phase can have dire implications at the point of implementation.

The third phase concerns running the model. It involves steps 8 (Experi- mental Design), 9 (Production Runs and Analysis), and 10 (Additional Runs). This phase must have a thoroughly conceived plan for experimenting with the simulation model. A discrete-event stochastic simulation is in fact a statistical experiment. The output variables are estimates that contain random error, and therefore a proper statistical analysis is required. Such a philosophy differs sharply from that of the analyst who makes a single run and draws an inference from that single data point.

The fourth phase, implementation, involves steps 11 (Documentation and Reporting) and 12 (Implementation). Successful implementation depends on continual involvement of the model user and the successful completion of every step in the process. Perhaps the most crucial point in the entire process is step 7 (Validation), because an invalid model is going to lead to erroneous results, which if implemented could be dangerous, costly, or both.