Chapter 1
Introduction to Simulation

Banks, Carson, Nelson & Nicol

Discrete-Event System Simulation

Introduction

- A "*simulation*" is the imitation of the operation of a real-world process or system ***over time***
  - A system consists of a set of *entities* or *objects*
- 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"***
- The "*model*" usually takes the form of a *"set of assumptions"* concerning the operation of the system
- The "*assumptions*" are expressed in mathematical, logical and symbolic relationships between the *entities* or *objects of interest* of the system

Introduction (continued ..)

- Once a "*proper model*" is developed and *validated*, the model can be used to investigate a wide variety of *"what if"* scenarios 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.
- Therefore, 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.

Introduction (continued ..)

- Solutions might be found by the use of differential calculus, probability theory, algebraic methods, or other mathematical techniques
  - *The solution usually consists of one or more numerical parameters, which are called **measures of performance** of the system.*
- Many real-world systems are so complex that models of these systems are virtually impossible to solve mathematically
  - 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.

Why Simulation tools?

The availability of:

- *Special-purpose simulation languages,*
- *Massive computing capabilities at a decreasing cost per operation,*
- *Advances in simulation methodologies*

have made simulation one of the most widely used and accepted tools in operations research and systems analysis

When Simulations are appropriate

1. Simulation enables the study of, and experimentation with, the *internal interactions* of a complex system or of a *subsystem* within a complex system **(Abstraction)**
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 during the designing of a simulation model could be of great value towards suggesting improvement in the system under investigation.
4. Changing simulation inputs and observing the resulting outputs can produce valuable insight into which variables are the most important and into how variables interact.

When Simulations are appropriate (contd..)

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 before implementation, so as to prepare for what might happen.
7. Simulation can be used to verify analytic solutions.
8. Simulating different capabilities for a machine can help determine the requirements on it.
9. Simulation models designed for training make learning possible without the cost and disruption of on-the-job instruction.

When Simulations are appropriate (contd..)

10. Animation shows a system in simulated operation so that the plan can be visualized.
11. Many modern systems (factory, wafer fabrication plant, service organization, etc.) are so complex that its internal interactions can be treated only through simulation.

Simulations are not appropriate IF

1. The problem can be solved by common sense
2. The problem can be solved analytically
3. It is easier to perform direct experiments
4. The costs exceed the savings
5. The resources or time are not available
6. No data is available, not even estimates as simulation takes data, sometimes lots of data.
7. There is not enough time or if the personnel are not available to verify and validate the model

Simulations are not appropriate IF

8. Managers have unreasonable expectations, if they ask for too much too soon, or if the power of simulation is overestimated (e.g., ***Simulation versus Emulation***)
9. The system behavior is too complex or can't be defined
   - e.g., Human behavior is sometimes extremely complex to model

Simulations are "Run"

- 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
- In contrast to optimization models, simulation models are "run" rather than "solved"
- Given a particular set of inputs 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 in the design new system, is then recommended for implementation

Advantages

- New policies, operating procedures, decision rules, information flows, organizational procedures, and so on can be explored without disrupting ongoing operations of the real system
- New hardware designs, physical layouts, transportation systems, and so on can be tested without committing resources for their acquisition.
- Hypotheses about how or why certain phenomena occur can be tested for feasibility.
- Time can be compressed or expanded to allow for a speed-up or slow-down of the phenomena under investigation

Advantages (continued …)

- Insight can be obtained about the interaction of variables.
- Insight can be obtained about the importance of variables to the performance of the system.
- Bottleneck analysis can be performed to discover where work in process, information, materials, and so on are being delayed excessively.
- A simulation study can help in understanding how the system operates rather than how individuals think the system operates.
- **"What if"** questions can be answered. This is particularly useful in the design of new systems.

Disadvantages

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 different competent individuals, they might have similarities, but it is highly unlikely that they will be the same.
2. Simulation results can be difficult to interpret. Most simulation outputs are essentially random variables (they are usually based on random inputs), so it can be hard to distinguish whether an observation is a result of system interrelationships or of randomness.

Disadvantages (contd ..)

3. Simulation modeling and analysis can be time consuming and expensive. Skimping on resources for modeling and analysis could result in a simulation model or analysis that is not sufficient to the task.
4. Simulation is used in some cases when an analytical solution is possible, or even preferable. This might be particularly true in the simulation of some waiting lines where closed-form queueing models are available

Areas of Application

- Winter Simulation Conference (WSC) (www.wintersim.org)
- WSC papers: www.informs-sim.org/wscpapers.html
- Manufacturing Applications
- Semiconductor Manufacturing
- Construction Engineering and Project Management
- Military Applications
- Logistics, Supply Chain and Distribution Applications
- Transportation Modes and Traffic
- Business Process Simulation
- Healthcare
- Networks, Systems, Protocols

System Environment

- 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 accomplishment of some purpose.
  - e.g., 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*
- In modeling systems, it is necessary to decide on the *boundary* between the system and its environment.
  - e.g., factors controlling the arrival of orders to a factory

Components of a system

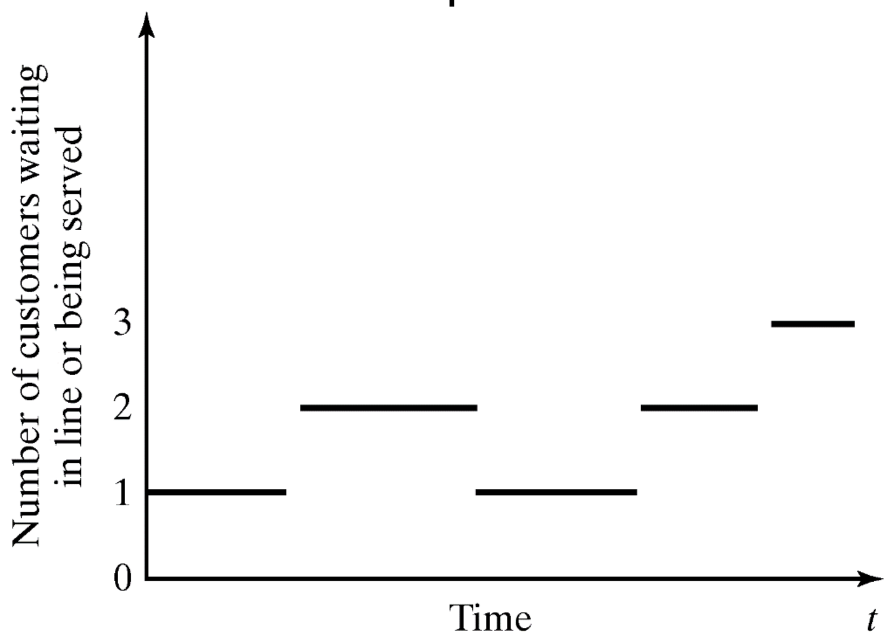
- To understand and analyze a system, a number of terms need to be defined:
  - An *entity* is an object of interest in the system.
  - An *attribute* is a property of an entity.
  - An *activity* represents a time period of specified length
  - The *state* of a system is defined to be that collection of variables necessary to describe the system at any time, relative to the objectives of the study.
  - An *event* is defined as an instantaneous occurrence that might change the state of the system.
  - The term *endogenous* is used to describe activities and events occurring within a system (e.g., completion of service)
  - The term *exogenous* is used to describe activities and events in the environment that affect the system (e.g., order arrival)

Examples of Systems and Components

System	***Entities***	***Attributes***	***Activities***	***Events***	***State Variables***
Banking	Customers	Checking Account balance	Making deposits	Arrival, Departure	# of busy tellers, # of waiting customers
Rapid Rail	Riders	Origin, Destination	Traveling	Arrival at station, Reached the destination	# of riders waiting at each station, # of riders in transit
Production	Machines	Speed, Capacity, rate of breakdown	Welding, stamping	breakdown	Status of machines (busy, idle or down)
Communications	Messages	Length, destination	Transmitting	Arrival at a destination	# waiting to be transmitted
Inventory	Warehouse	Capacity	Withdrawing	Demand	Level of inventory backlog

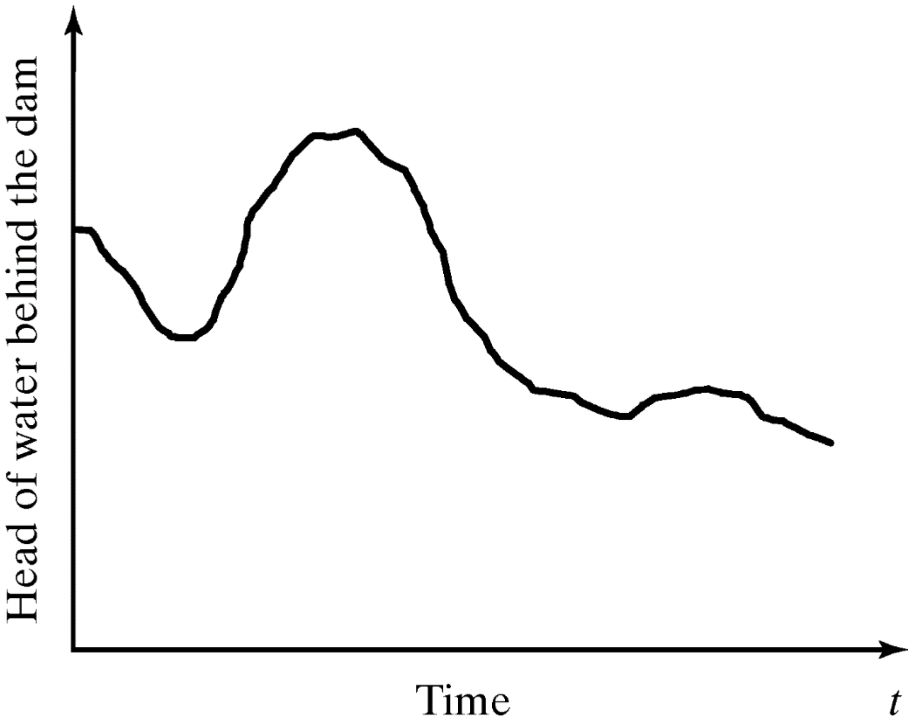
Types of Systems

- Systems can be categorized as ***discrete*** or ***continuous***.
- A *discrete* system is one in which the state variable(s) change only at a discrete set of points in time.
  - E.g., Bank: 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



Types of Systems (continued ..)

- A *continuous* system is one in which the state variable(s) change continuously over time.
  - An example is the head of water behind a dam.



Model of a System

- A ***model*** is defined as a representation of a system for the purpose of studying the system
  - New designs from scratch, existing systems, modifications
- For most studies, **it is only necessary** to consider those aspects of the system that affect (or relevant) the problem under investigation.
- These aspects are represented in a model of the system
- The model, by definition, is a simplification of the system.
- On the other hand, the model should be sufficiently detailed to permit valid conclusions to be drawn about the real system.
- Different models of the same system could be required as the purpose of investigation changes

Types of models

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

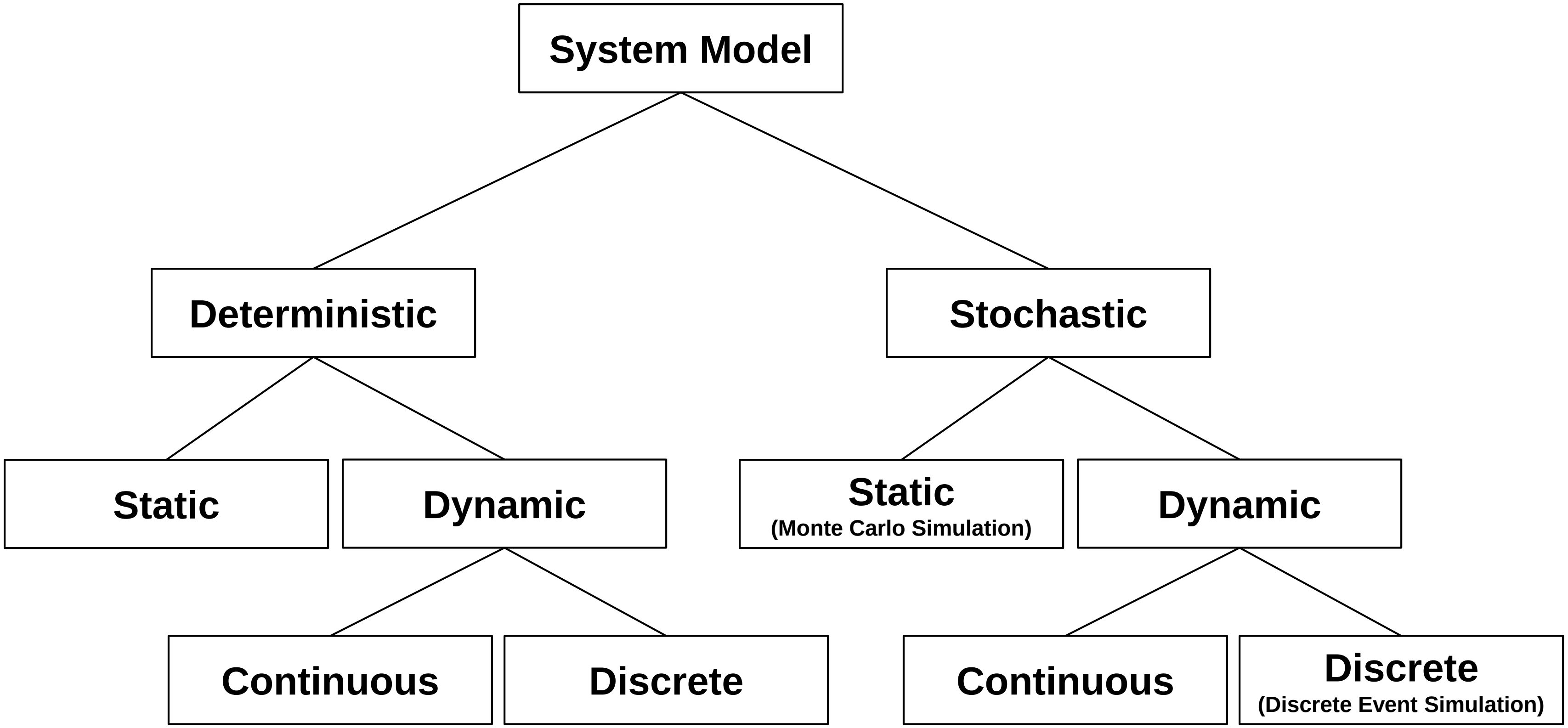
Types of models (continued ..)

- 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.
  - e.g., 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 inter-arrival times and random service times.
  - 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

Types of models (continued ..)

- *Discrete* models and *Continuous* models are defined analogous to systems (Slide 17)
- 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
- 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 function of the characteristics of the system and the objective of the study.
  - 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 via continuous simulation could be more appropriate

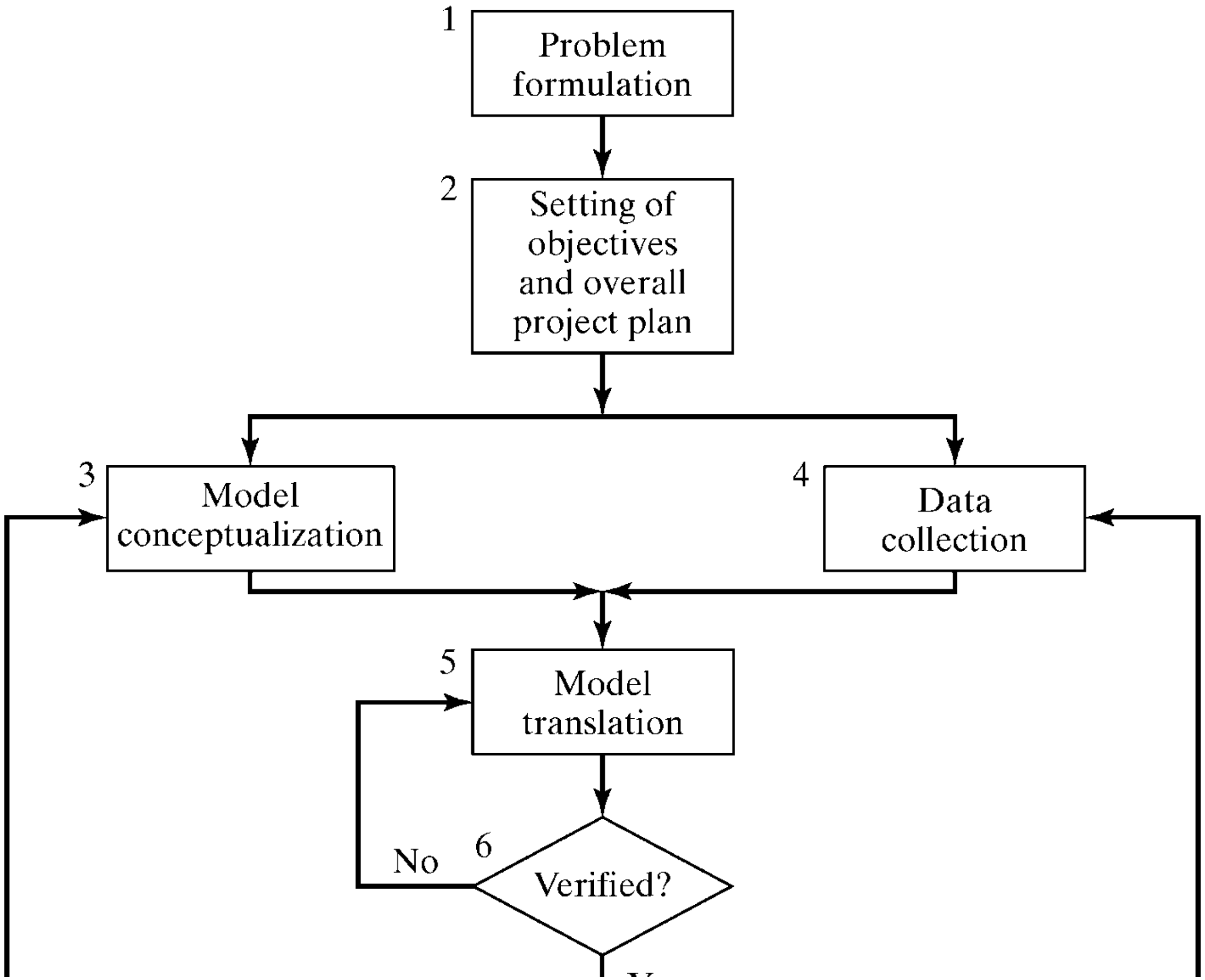
System Model Taxonomy



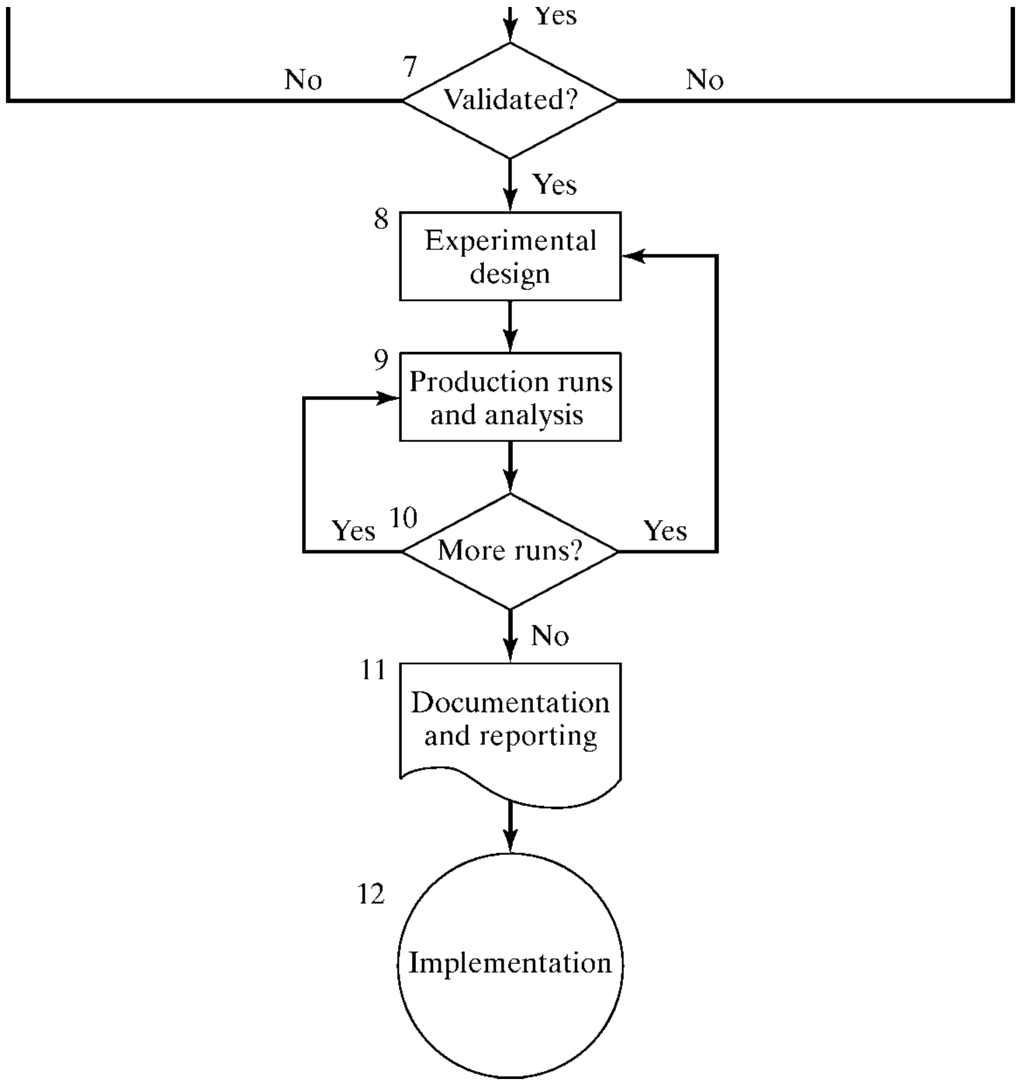
Discrete Event Simulation

- This course is about Discrete Event Simulations. Therefore, the ***models considered are discrete, dynamic, and stochastic***
- Discrete-event systems simulation is 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 methods rather than by analytical methods
  - Analytical methods employ the deductive reasoning of mathematics to "solve" the model
  - 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 generated from the model assumptions, and observations are collected to be analyzed and to estimate the true system performance measures

Steps in a Simulation Study



Steps in a Simulation Study (continued ..)



Steps

- *Problem formulation:* Every study should begin with a statement of the problem
- *Setting of objectives and overall project plan:* The objectives indicate the questions to be answered by simulation. A determination should be made concerning whether simulation is the appropriate methodology for the problem as formulated and objectives as stated.
- *Model conceptualization:* The construction of a model of a system is probably as much art as science. 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
- *Data collection:* There is a constant interplay between the construction of the model and the collection of the needed input data

Steps (continued ..)

- *Model translation*: Most real-world systems result in models that require a great deal of information storage and computation, so the model must be entered into a computer-recognizable format. General purpose or special purpose simulation languages or packages to be used is determined here.
- *Verified?:* Verification pertains to the computer program prepared for the simulation model. Is the computer program performing properly?
- *Validated?:* Validation usually is achieved through the calibration of the model, an iterative process of comparing the model against actual system behavior and using the discrepancies between the two, and the insights gained, to improve the model.
- *Experimental design:* The alternatives that are to be simulated must be determined. Often, the decision concerning which alternatives to simulate will 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 replications to be made of each run.

Steps (continued ..)

- *Production runs and analysis*: Production runs, and their subsequent analysis, are used to estimate measures of performance for the system designs that are being simulated.
- *More Runs?:* Given the analysis of runs that have been completed, the analyst determines whether additional runs are needed and what design those additional experiments should follow.
- *Documentation and reporting:* There are two types of documentation: program 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 could be necessary to understand how the program operates and what parameters used.
  - 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 experiments, and the recommended solution to the problem