Simulation and Modeling (CS302)

Lecture 01: Introduction

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Agenda

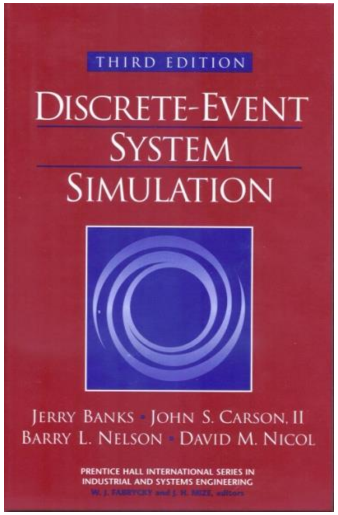
Preface

<u>Lecture notes of this course are collected and edited from:</u>

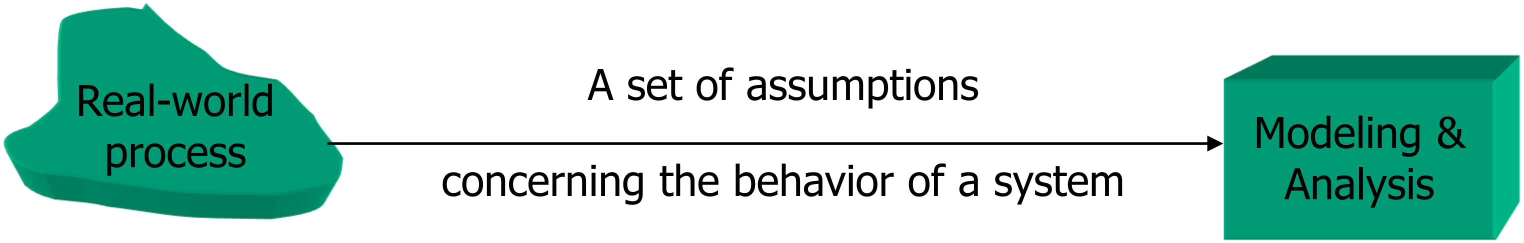
- Textbook: J. Banks, J. S. Carson, B. L. Nelson, D. M. Nicol, “Discrete-event System Simulation”, 3rd edition
- Lecture Notes: Prof. Moheb G. Ramzy, Faculty of Science, Minia University, “Simulation and Modeling Course”

<u>Full Mark: 100</u>

- Lab: 10
- Oral: 10
- Midterm: 10
- Periodical Tasks: 10
- Final: 60



Introduction to Simulation



- **Simulation**
  - is the imitation of the operation of a real-world process or system over time
  - to develop a set of assumptions of mathematical, logical, and symbolic relationship between the entities of interest, of the system.
  - to estimate the measures of performance of the system with the simulation-generated data

- **Simulation Modeling can be used**
  - as an analysis tool for predicting the effect of changes to existing systems
  - as a design tool to predict the performance of new systems

Introduction to Simulation

- **<u>Simulation</u>** 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 **<u>simulation model</u>**:
  - 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 **<u>"what if"</u>** questions about the real-world system.

Simulation Application areas

The Following is a list of some particular kinds of problems for which simulation has been found to be a useful and powerful tool:

1. Designing and analyzing manufacturing systems.
2. Evaluating military weapons systems or their logistics requirements.
3. Determining hardware requirements or protocols for communications networks.
4. Designing and operating transportation systems such as airports, freeways, ports, and subways.
5. Evaluating designs for service organizations such as: fast-food restaurants, hospitals, and post offices.
6. Determining ordering policies for an inventory system.
7. Analyzing financial or economic systems.

Simulation Application areas

<u>In more details:</u>

- Manufacturing Applications
  - Analysis of electronics assembly operations
  - 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

- Semiconductor Manufacturing
  - Comparison of dispatching rules using large-facility models
  - The corrupting influence of variability

- Human Systems
  - Modeling human performance in complex systems
  - Studying the human element in air traffic control

Simulation Application areas

<u>In more details:</u>

- Construction Engineering
  - Construction of a dam embankment
  - Activity scheduling in a dynamic, multi-project setting
  - Investigation of the structural steel erection process
  - Special-purpose template for utility tunnel construction

- Military Application
  - 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 non-war fighting operations
  - Multi-trajectory performance for varying scenario sizes
  - Using adaptive agent in U.S Air Force pilot retention

Simulation Application areas

<u>In more details:</u>

- Logistics, Transportation, and Distribution Applications
  - Evaluating the potential <u>benefits</u> of a rail-traffic planning algorithm
  - <u>Evaluating strategies</u> to improve railroad performance
  - Parametric modeling in <u>rail-capacity planning</u>
  - <u>Analysis of passenger flows</u> in an airport terminal
  - <u>Proactive flight-schedule evaluation</u>
  - Logistics issues in autonomous food production systems for extended-duration space exploration

- Business Process Simulation
  - Product development program planning
  - Reconciliation of business and systems modeling
  - Personnel forecasting and strategic workforce planning

When Simulation is the Appropriate Tool

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. By changing simulation inputs and observing the resulting outputs, valuable insight may be obtained into which variables are most important and how variables interact.
3. Informational, organizational, and environmental changes can be simulated, and the effect of these alterations on the model's behavior can be observed.
4. The knowledge gained in designing a simulation model may be of great value toward suggesting improvement in the system under investigation.
5. Simulation can be used to verify analytic solutions.
6. Simulating different capabilities for a machine to determine requirements.
7. Simulation models designed for training allow learning without the cost and disruption of on-the-job learning.

Main Concepts (Terminologies)

- **System**: a collection of entities, e.g., people or machines, that act and interact together toward the accomplishment of some logical end.
- **System Environment**: changes occurring outside the system.

Main Components of a System:

- **Entity:** is an object of interest in the system.
- **Attribute:** is a property of an entity.
- **Activity:** represents a time period of specified length.
- **State**: the collection of variables necessary to describe the system at any time, relative to the objectives of the study.
- **Event**: an instantaneous occurrence that may change the state of the system.
  - **Endogenous**: to describe activities and events occurring within a system.
  - **Exogenous**: to describe activities and events in an environment that affect the system.

Main Concepts (Terminologies)

- **Model**
  - a representation of a system for the purpose of studying the system
  - a simplification/abstraction of the system
  - sufficiently detailed to permit valid conclusions to be drawn about the real system

Examples for System 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

Main Concepts (Terminologies)

<u>Examples for System Components:</u>

- Customers might be one of the **<u>entities</u>**, the balance in their checking accounts might be an **<u>attribute</u>**, and making deposits might be an **<u>activity</u>**.
- The **<u>state</u>** of a system is defined to be the collection of variables necessary to describe the system at any time, relative to the objective of the study.
  - Example: 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 **<u>event</u>** is defined as an instantaneous occurrence that may change the state of the system.
- The term **<u>endogenous</u>** is used to describe activities and events occurring within a system, and the term **<u>exogenous</u>** is used to describe activities and events in the environment that affect the system.
  - Example: the arrival of a customer is an exogenous event, and the completion of service of a customer is an endogenous event.

Systems Categories

Systems can be categorized as discrete or continuous.

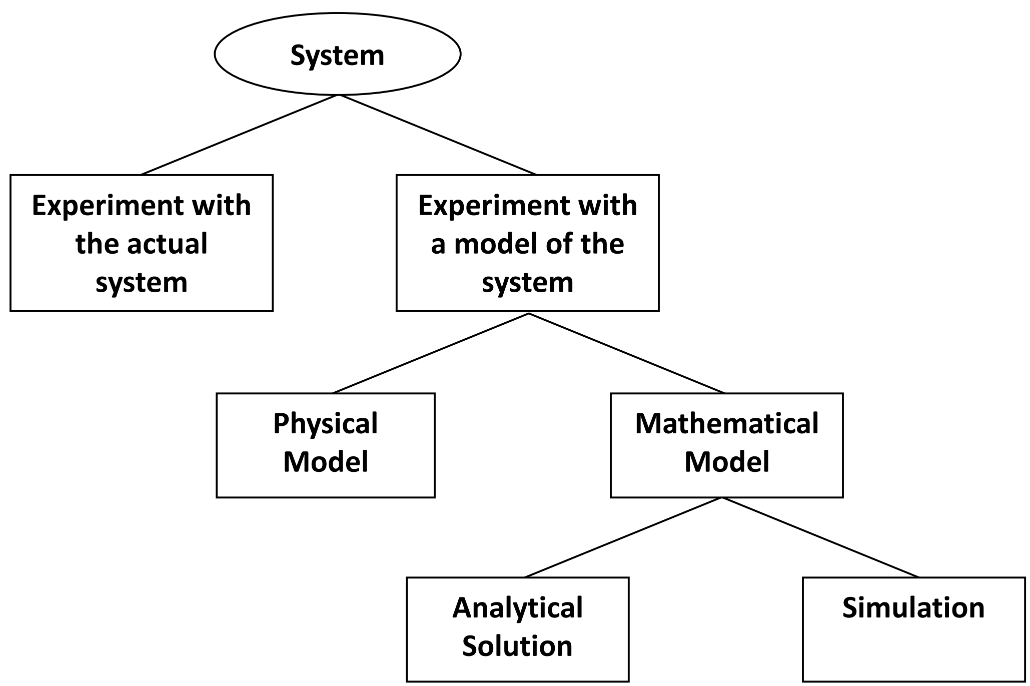
- A ***discrete system*** is one in which the state variable(s) change only at discrete set of points in time.
  - A bank is an example of a discrete system, since state variables – e.g. the number of customers in the bank – change only when a customer arrives or when a customer finishes being served and departs.

- A ***continuous system*** is one in which the state variable(s) change continuously over time.
  - An airplane moving through the air is an example of a continuous system, since state variables such as position and velocity can change continuously with respect to time.

Ways of Studying a System

- At some point in the lives of most systems, there is a need to study them to try to gain some insight into the relationships among various components, or to predict performance under some new conditions being considered.

The following figure maps out different ways in which a system might be studied.



Ways of Studying a System …

- If it is possible and cost-effective to alter the system physically and then let it operate under the new conditions, it is probably desirable to do so. However, it is rarely feasible to do this, because:
  - such an experiment would often be too costly or disruptive to the system, or
  - the system might not even exist, but we want to study it to see how it should be built.

→For these reasons, it is usually necessary to build a model as a representation of the system and study it as a surrogate for the actual system.

Ways of Studying a System …

- Occasionally, it has been found useful to build *physical models* to study engineering or management systems. But the vast majority of models built for such purposes are *mathematical*.
- *A mathematical model* represents a system in terms of logical and quantitative relationships that are then manipulated and changed to see how the model reacts.
- Once we have built a mathematical model, it must then be examined to see how it can be used to answer the questions of interest about the system it is supposed to represent.

Ways of Studying a System …

- If the model is simple enough, it may be possible to work with its relationships and quantities to get an exact, analytical solution.
- However, many systems are highly complex, so that valid mathematical models of them are themselves complex, precluding any possibility of an analytical solution.
- In this case, the model must be studied by means of simulation, i.e., numerically exercising the model for inputs in question to see how they affect the output measures of performance.

Classification of Simulation Models

The mathematical model to be studied by means of simulation will be referred to as a ***simulation model***. We can classify simulation models along three different dimensions:

(1) Static vs. Dynamic Simulation Models

- A ***static simulation model*** is a representation of a system at a particular time, or one that may be used to represent a system in which time plays no role, such as Monte Carlo Models.
- A ***dynamic simulation model*** represents a system as it evolves over time, such as a conveyor system in a factory.

Classification of Simulation Models …

(2) Deterministic vs. Stochastic Simulation Models

- If a simulation model does not contain any probabilistic (i.e., random) components, it is called ***deterministic***. In deterministic models, the output is "determined" once the set of input quantities and relationships in the model have been specified, such as a system of differential equations describing a chemical reaction.
- If a simulation model has some input random components, it is called ***stochastic***. Most queuing and inventory systems are modeled stochastically. Stochastic simulation models produce output that is itself random, and must be treated as only an estimate of the true characteristics of the model.

Classification of Simulation Models …

(3) Continuous vs. Discrete Simulation Models

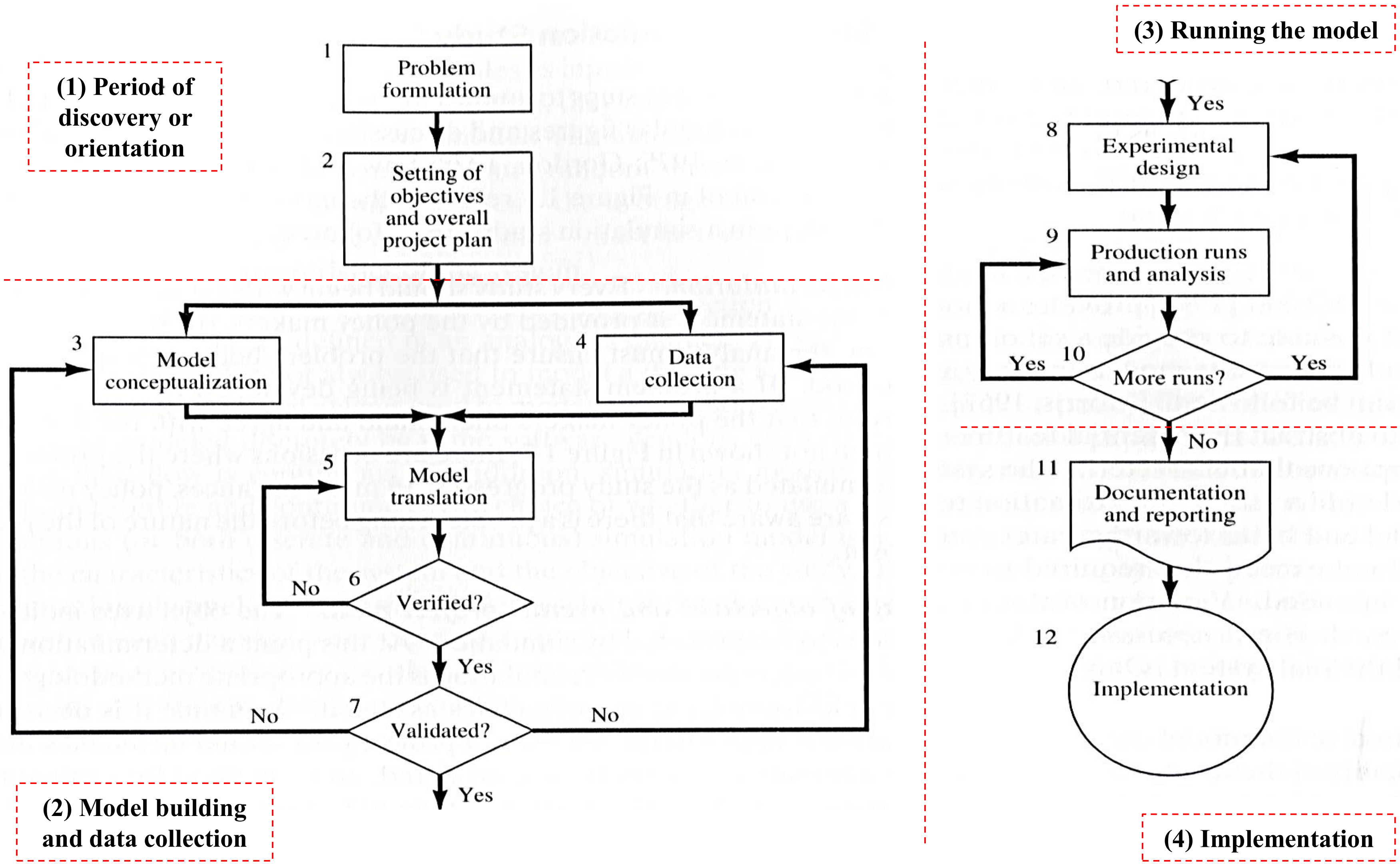
- These models are defined analogously to the way discrete and continuous systems were defined before.
- It should be mentioned that a discrete model is not always used to model a discrete system, and vice versa. The decision whether to use a discrete or a continuous model for a particular system depends on the specific objectives of the study.

The simulation models we consider in this course will be *discrete*, *dynamic*, and *stochastic* and will henceforth be called ***discrete-event simulation models***.

Simulation models are analyzed by numerical 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.

A Flowchart for modeling a Simulation



Main Steps for modeling a Simulation

1. **Problem formulation**: Policy maker/Analyst understand and agree with the formulation.
2. **Setting of objectives and overall project plan**
3. **Model conceptualization**
   - The 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.
4. **Data collection**
   - As the complexity of the model changes, the required data elements may also change.
5. **Model translation**: special-purpose simulation software
6. **Verified?**
   - Is the computer program performing properly? (has the recommended features)
   - Debugging for correct input parameters and logical structure (initial test)
7. **Validated?**
   - The determination that a model is an accurate representation of the real system. (acceptance testing).
   - Validation is achieved through the calibration of the model (Integration test)

Main Steps for modeling a Simulation

8. Experimental design
   - The decision on the length of the initialization period, the length of simulation runs, and the number of replications to be made of each run.
9. Production runs and analysis
   - To estimate measures of performances
10. More runs?
11. Documentation and reporting
    - Program documentation : for the relationships between input parameters and output measures of performance, and for a modification
    - Progress documentation : the history of a simulation, a chronology of work done and decision made.
12. Implementation

Discrete-Event Simulation

- ***Discrete-event simulation*** concerns the modeling of a system as it evolves over time by a representation in which the state variables change instantaneously at separate points in time. These points in time are the ones at which an event occurs.

Example:

- Consider a service facility with a single server -e.g., an information desk at an airport- for which we would like to estimate the (expected) average delay in queue (line) of arriving customers, where the delay in queue of a customer is the length of the time interval from the instant of his arrival at the facility to the instant he begins being served.

- For the objective of estimating the average delay of a customer, the state variables for a discrete-event simulation model of the facility would be:
  - the status of the server, i.e., either idle or busy,
  - the number of customers waiting in queue to be served (if any), and
  - the time of arrival of each person waiting in queue.

➢ The status of the server is needed to determine, upon a customer's arrival, whether the customer can be served immediately or must join the end of the queue.

➢ When the server completes serving a customer, the number of customers in the queue is used to determine whether the server will become idle or begin serving the next customer in the queue.

- The time of arrival of a customer is needed to compute his delay in queue, which is the time he begins being served minus his time of arrival.

- There are two types of events for this system:
  - the arrival of a customer and
  - the completion of a service for a customer, which results in the customer departure.
- An ***arrival*** is an event since it causes the (state variable) server status to change from idle to busy or the (state variable) number of customers in the queue to increase by 1.
- Correspondingly, a ***departure*** is an event because it causes the server status to change from busy to idle or the number of customers in the queue to decrease by 1.