Chapter One
Introduction to Modeling and Simulation

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Outline

Introduction

- A system is defined as a group of objects that interact with each other to accomplish some purpose
  - A computer system: CPU, memory, disk, bus, NIC
  - An automobile factory: Machines, components parts and workers operate jointly along assembly line
- A system is often affected by changes occurring outside the system: system environment
  - Hair salon: arrival of customers
  - Warehouse: arrival of shipments, fulfilling of orders
  - Effect of supply on demand: relationship between factory output from supplier and consumption by customers

Introduction

- A system is defined to be a collection of entities, e.g., people or machines, that act and interact together toward the accomplishment of some logical end. [This definition was proposed by Schmidt and Taylor (1970).]
- In practice, what is meant by "the system" depends on the objectives of a particular study.
- The state of a system defined to be that collection of variables necessary to describe a system at a particular time, relative to the objectives of a study.
  - In a study of a bank, examples of possible state variables are the number of busy tellers, the number of customers in the bank, and the time of arrival of each customer in the bank.

Introduction

- Entity
  - An object of interest in the system: Machines in factory
- Attribute
  - The property of an entity: speed, capacity, failure rate
- State
  - A collection of variables that describe the system in any time: status of machine (busy, idle, down,…)
- Event
  - An instantaneous occurrence that might change the state of the system: breakdown

Introduction

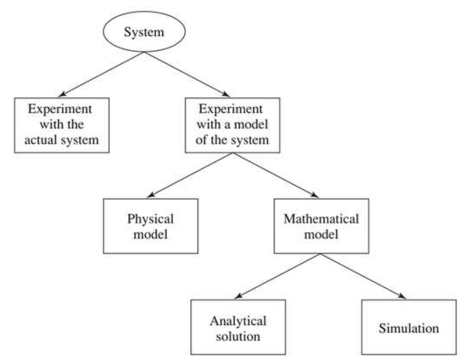
- **What is Model?**
  - An abstract representation of a (real) system that captures the essential characteristics or properties of the system
  - Often requires making simplifying assumptions about how the system actually works
- Models are high-level representations of the operation of a real-world process or system.
- Our concern will be with models that are
  - Discrete (vs. continuous)
  - Stochastic (vs. deterministic)
  - Dynamic (vs. static)
- How can you “solve” a model?
  - Analytic methods
  - Numerical methods
  - Simulation methods

Introduction

- There are two types of systems, discrete and continuous.
- **A discrete system** is one for which the state variables change instantaneously at separated points in time.
  - A bank is an example of a discrete system, since state variables change only when a customer arrives or when a customer finishes being served and departs.
- **A continuous system** is one for which the state variables change continuously with respect to 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.

Introduction

- 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.



Introduction

- ***Experiment with Actual vs with a Model of a system***
- The "system" might not even exist, but we nevertheless want to study it in its various proposed alternative configurations to see how it should be built in the first place;
  - examples of this situation might be a proposed communications network, or a strategic nuclear weapons system.
- 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.
- When using a model, there is always the question of whether it accurately reflects the system for the purposes of the decisions to be made

Introduction

- ***Physical Model vs Mathematical Model***
- the word "model" evokes images of clay cars in wind tunnels, cockpits disconnected from their airplanes to be used in pilot training, or miniature supertankers scurrying about in a swimming pool.
- These are examples of physical models (also called iconic models), and are not typical of the kinds of models that are usually of interest in operations research and systems analysis.
- Occasionally, however, it has been found useful to build physical models to study engineering or management

Introduction

- ***Physical Model vs Mathematical Model***
- Mathematical Model represents a system in terms of logical and quantitative relationships that are then manipulated and changed to see how the model reacts, and thus how the system would react—if the mathematical model is a valid one.
- Perhaps the simplest example of a mathematical model is the familiar relation d =rt, where r is the rate of travel, t is the time spent traveling, and d is the distance traveled.

Introduction

- ***Analytical Solution vs Simulation***
- 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. If the model is simple enough, it may be possible to work with its relationships and quantities to get an exact, analytical solution.
- but some analytical solutions can become extraordinarily complex, requiring vast computing resources; inverting a large nonsparse matrix is a well-known example of a situation in which there is an analytical formula known in principle, but obtaining it numerically in a given instance is far from trivial.
- If an analytical solution to a mathematical model is available and is computationally efficient, it is usually desirable to study the model in this way rather than via a simulation.
- 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,

Types of Models

***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 simply plays no role**;
- A dynamic simulation model represents a system as it evolves over time, such as a conveyor system in a factory.

Types of Models

***Deterministic vs. Stochastic Simulation Models*.**

- If a simulation model does not contain any probabilistic (i.e., random) components, it is called deterministic; a complicated (and analytically intractable) system of differential equations describing a chemical reaction might be such a model.
- In deterministic models, the output is "determined" once the set of input quantities and relationships in the model have been specified, even though it might take a lot of computer time to evaluate what it is.
- Many systems, however, must be modeled as having at least some random input components, and these give rise to stochastic simulation models.

Types of Models

***Deterministic vs. Stochastic Simulation Models*.**

- Most queueing and inventory systems are modeled stochastically.
- Stochastic simulation models produce output that is itself random, and must therefore be treated as only an estimate of the true characteristics of the model;

Types of Models

***Continuous vs. Discrete Simulation Models*.**

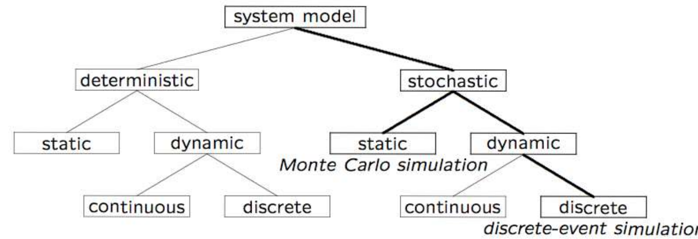
- Most queueing and inventory systems are modeled stochastically.
- Stochastic simulation models produce output that is itself random, and must therefore be treated as only an estimate of the true characteristics of the model;

Simulation Models

- Develop a simulation program that implements a computational model of the system of interest
- Run the simulation program and use the data collected to estimate the performance measures of interest (often involves the use of randomization)
- A system can be studied at an arbitrary level of detail
- Quote of the day:

> "The hardest part about simulation is deciding what NOT to model."
> - Moe Lavigne, Stentor, Summer 1995

Simulation



Simulation

- Imitate the operations of a facility or process, usually via computer
  - What's being simulated is the system
  - To study system, often make assumptions/approximations, both logical and mathematical, about how it works
  - These assumptions form a model of the system
  - If model structure is simple enough, could use mathematical methods to get exact information on questions of interest — analytical solution

Computer Simulation

- Methods and applications to imitate or mimic real systems usually via computer.
- No longer regarded as the approach of "last resort".
- Today, it is viewed as an indispensable problem-solving methodology for engineers, designers, and managers.
- Can be used to study simple models but should not use it if an analytical solution is available
- Real power of simulation is in studying complex models

Application of Simulation

- Applies in many fields and industries
  - Manufacturing facility
  - Bank operation
  - Airport operations (passengers, security, planes, crews, baggage)
  - Transportation/logistics/distribution operation
  - Hospital facilities (emergency room, operating room, admissions)
  - Computer network
  - Business process (insurance office)
  - Criminal justice system
  - Chemical plant
  - Fast-food restaurant
  - Supermarket
  - Emergency-response system

Advantages of Simulation

- Flexibility to model things as they are (even if messy and complicated) - Allows uncertainty, non stationarity in modeling
- Insight can be obtained about the interactions of variables, and which ones have the most impact on system performance
- New designs can be tested without committing resources for their acquisition
- New policies, operating procedures can be explored without disrupting ongoing operation of the real system.
- New hardware designs, physical layouts, transportation systems can be tested without committing resources for their acquisition.
- Time can be compressed or expanded to allow for a speed-up or slow-down of the phenomenon
- Can obtain answers to "What if…" questions
- Advances in simulation software, computing and information technology are all increasing popularity of simulation

Disadvantages of Simulation

- Model building requires special training
  - Vendors of simulation software have been actively developing packages that contain models that only need input (templates), which simplifies things for users
- Simulation results can be difficult to interpret
  - Need proper statistical interpretation for output analysis
- Simulation modeling and analysis can be time- consuming and expensive, both for the modeler, as well as in compute time (if not done wisely)

Simulation is not appropriate if …

- the problem can be solved by common sense
- the problem can be solved analytically
- it is easier to perform direct experiments
- the cost of simulations exceeds (expected) savings for the real system
- the system behavior is too complex (e.g., humans)

Common mistakes in Simulation

- Poor (pseudo) random number generators
  - Best to use well-known or well-understood generator
- Improper selection of seeds for PRNG
  - Short periods; same seeds for all streams
- Inappropriate level of detail:
  - More detail => more time => more bugs
  - More parameters ≠ more accurate
- Improperly handled initial conditions (warmup)
- Improperly handled ending conditions (cooldown)
- Run-length too short to achieve steady-state
- Need proper output analysis, confidence intervals

Types of Simulation

- Monte Carlo simulation
- Time-stepped simulation
- Trace-driven simulation
- Discrete-event simulation
- Continuous simulation

Monte Carlo Simulation

Named after Count Montgomery de Carlo, who was a famous Italian gambler and random-number generator (1792-1838).

- Static simulation (no time dependency)
- To model probabilistic phenomenon
- Can be used for evaluating non-probabilistic expressions using probabilistic methods
- Can be used for estimating quantities that are "hard" to determine analytically or experimentally

Trace-Driven Simulation

- Trace = time-ordered record of events in system
- Trace-driven simulation = Trace input
- Often used in evaluating or tuning resource management algorithms (based on real workloads):
- Paging, cache analysis, CPU scheduling, deadlock prevention, dynamic storage allocation
- Example: Trace = start time + duration of processes
- Example: Trace = size in bytes of file written to disk
- Example: Trace = mobile device ID and call duration

Advantage of Trace-Driven Simulation

- Credibility
- Easy validation: compare simulation with measurement
- Accurate workload: models correlation and interference
- Fair comparison: better than random input
- Similarity to the actual implementation:
  - trace-driven model is similar to the system
  - can understand complexity of implementation

Disadvantage of Trace-Driven Simulation

- Complexity: more detailed
- Representativeness: workload changes with time, equipment
- Data Collection: few minutes fill up a disk
- Instrumentation: granularity; intrusiveness
- Single Point of Validation: one trace = one point
- Difficult to change workload

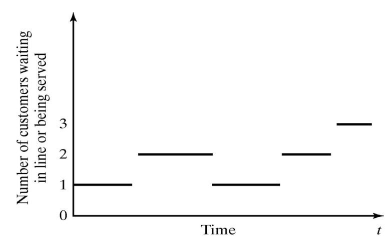
Discrete-Event Simulation

- A simulation model with three features:

1. Stochastic:
   some variables in the simulation model are random
2. Dynamic:
   system state evolves over time
3. Discrete-Event:
   changes in system state occur at discrete time instances

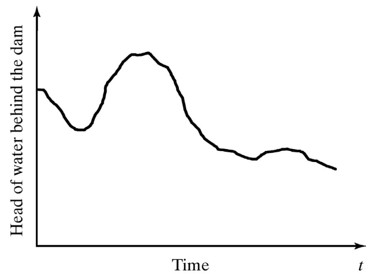
Discrete-Event Simulation

- A **discrete system** is one in which the system state changes only at a discrete set of points in time
- Example: A restaurant



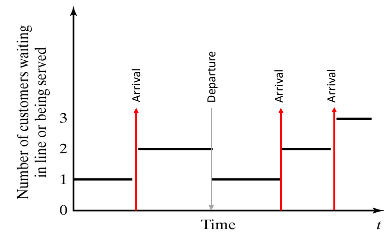
Continuous Simulation

- A **continuous system** is one in which the system state changes continuously over time
- Example: Water level in Bow River (or Bearspaw dam)



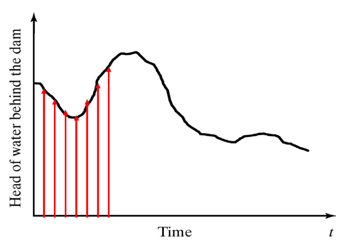
Discrete-Event Simulation

- A simulation model in which system state evolves over a discrete sequence of events in time
  - System state changes only when an event occurs
  - System state does not change between the events



Continuous Simulation

- A simulation model in which system state evolves continuously over time
  - Time is divided to small time slices
  - System state changes in every time slice



Characterizing a Simulation Model

- Deterministic or Stochastic
  - Does the model contain stochastic components?
- Static or Dynamic
  - Is time a significant variable?
- Continuous or Discrete
  - Does the system state evolve continuously or only at discrete points in time?

DES Model Development

- How to develop a simulation model:
  1. Determine the goals and objectives
  2. Build a **conceptual** model
  3. Convert into a **specification** model
  4. Convert into a **computational** model
  5. Verify the model
  6. Validate the model
- Typically an iterative process

Three Model Levels

- **Conceptual Model**
  - Very high level (perhaps schematic diagram)
  - How comprehensive should the model be?
  - What are the state variables?
  - Which ones are dynamic, and which are most important?
- **Specification Model**
  - On paper: entities, interactions, requirements, rules, etc.
  - May involve equations, pseudocode, etc.
  - How will the model receive input?
- **Computational Model**
  - A computer program
  - General-purpose programming language or simulation language?

Simulation Software

- General purpose programming languages
  - Flexible and familiar
  - Well suited for learning DES principles and techniques
  - E.g., C++, Java
- Simulation programming languages
  - Good for building models quickly
  - Provide built-in features (e.g., queue structures)
  - Graphics and animation provided
  - Domain specific
    - ✓Network protocol simulation: ns2, Opnet
    - ✓Electrical power simulation: ETAP
    - ✓Design and engineering: Ansys, Autodesk
    - ✓Process simulation: Simul8
    - ✓System simulation: Vensim, Arena, Anylogic …

Verification and Validation

- **Verification**
  - Computational model should be consistent with specification model
  - Did we build the model right?
- **Validation**
  - Computational model should be consistent with the system being analyzed
  - Did we build the right model?
  - Can an expert distinguish simulation output from system output?