Modelling and Simulation

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Why Modelling and Simulation?

- The lives of individuals, the future development of a region, and even the global future often depend on dynamic systems whose processes and behavior we do not understand sufficiently.
- The examples range from bridges, aircraft, vehicles, social processes, urban development, population explosion, wars, environmental pollution to global climate change
- Knowing what will happen or might happen under certain circumstances may therefore be a matter of life and death-not just a matter of curiosity.
- To predict how a dynamic system will respond under certain conditions is often difficult even for simple systems.
- A model is sought that would be able to simulate behavior and to provide hints concerning necessary actions to avoid inadmissible or even dangerous developments.

How can we simulate?

- The **Description of behavior** from observations of one or several identical systems, observing how it behaves (output) under different conditions (input).
- Use a convenient mathematical relationships to relate input to output and imitate the behavior of the real system using these relationships which usually have nothing to do with the real processes in the system.
- The system is not described in all of its details and functions; it is treated as a "black box."

How can we Simulate?

- The **Explanation of behavior:** by modeling the actual processes of the real system.
- Much has to be known about the system itself: Of what parts is it composed? How are they connected? How do they influence each other?
- Past observed behavior is only of secondary interest; the emphasis is on the description of structure and processes.
- Using this information, the system behavior is modeled in form of a mathematical model/electrical or Mechanical analogue and can be simulated even for conditions not observed in the past.

Computer Simulation

The **Computer Simulation** has superseded all other options of modeling now a days due to the following advantages:

1. Independently of the type of system considered, computer simulations allow the use of a common methodology and generally applicable software programs.
2. The costs of model construction and simulation are usually only a fraction of the costs of real or analog physical models.
3. The time course of dynamic behavior can be significantly shortened or lengthened. Very fast processes of nature can be slowed down and studied in detail in the simulation; very slow processes can be speed up.
4. Dynamics that would lead to the destruction of the real system have no consequences on the computer model: the simulation program can be used over and over. This allows in particular the detailed investigation of dangerous system developments.
5. There is no risk for the real system.

When Simulation is appropriate?

The availability of special-purpose simulation languages, of massive computing capabilities at a decreasing cost per operation, and of advances in simulation methodologies have made simulation one of the most widely used and accepted tools in operations research and systems analysis.

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 during the designing of a simulation model could be of great value toward suggesting improvement in the system under investigation.
4. Changing simulation inputs and observing the resulting outputs can produce valuable insights about which variables are the most important and how variables interact.
5. Simulation can be used as a pedagogical device to reinforce analytic solution methodologies.

When Simulation is appropriate?

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 its requirements.

9. Simulation models designed for training make learning possible, without the cost and disruption of on-the-job instruction.

10. Animation can show a system in simulated operation so that the plan can be visualized.

11. A modern system (factory, wafer fabrication plant, service organization, etc.) is so complex that its internal interactions can be treated only through simulation.

When Simulation is not appropriate?

Simulation should not be used / not appropriate:

1. When the problem can be solved using common sense.
2. If the problem can be solved analytically.
3. If it is easier to perform direct experiments.
4. If the costs exceeds savings.
5. If the resources or time are not available.
6. Simulation requires data, no data is available, not even estimate simulation is not advised.
7. Simulation require verification and validation, if there is not enough time or the people are not available, simulation is not appropriate.
8. If there are unreasonable expectation say, too much soon – or the power of simulation is over estimated, simulation may not be appropriate.
9. If system behavior is too complex or cannot be defined, simulation is not appropriate

Advantages of simulation

1. Policies, operating procedures, decision rules, information flows, organizational 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 to allow for a speed-up or slow-down 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 to discover where work in process, information, materials, and so on are being delayed excessively.
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.

Disadvantages of simulation

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 the result of system interrelationships or of randomness.
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.

Areas of Application

Manufacturing Applications

Methodology for Selecting the Most Suitable Bottleneck Detection Method
Automating the Development of Shipyard Manufacturing Models
Emulation in Manufacturing Engineering Processes
Optimized Maintenance Design for Manufacturing Performance Improvement
Productivity Management in an Automotive-Parts Industry
Manufacturing Line Designs in Japanese Automobile Manufacturing Plants

Wafer Fabrication

A Paradigm Shift in Assigning Lots to Tools
Scheduling a Multi-Chip Package Assembly Line with Reentrant Processes
Execution Level Capacity Allocation Decisions for Assembly—Test Facilities
Managing WIP and Cycle Time with the Help of Loop Control

Areas of Application

Business Processing

A New Policy for the Service Request Assignment Problem
Process Execution Monitoring and Adjustment Schemes
In-Store Merchandizing of Retail Stores
Sales Forecasting for Retail Small Stores

Construction Engineering and Project Management

Scheduling of Limited Bar-Benders over Multiple Building Sites
Constructing Repetitive Projects
Traffic Operations for Improved Planning of Road Construction Projects
Template for Modeling Tunnel Shaft Construction
Decision Support Tool for Planning Tunnel Construction

Areas of Application

Logistics, Transportation, and Distribution

Operating Policies for a Barge Transportation System
Dispensing Plan for Emergency Medical Supplies in the Event of Bioterrorism
Analysis of a Complex Mail Transportation Network
Improving the Performance of Container Terminals
Yard Crane Dispatching Based on Real Time Data
Unit Loading Device Inventory in Airline Operations
Inventory Systems with Forecast Based Policy Updating
Dock Allocation in a Food Distribution Center
Operating Policies for a Barge Transportation System

Areas of Application

Military Applications

Multinational Intra-Theatre Logistics Distribution
Examining Future Sustainability of Canadian Forces Operations
Feasibility Study for Replacing the MK19 Automatic Grenade Launching System
Training Joint Forces for Asymmetric Operations
Multi-Objective Unmanned Aerial Vehicle Mission Planning
Development of Operational Requirements Driven Federations

Areas of Application

Health Care

Interventions to Reduce Appointment Lead-Time and Patient No-Show Rate
Supporting Smart Thinking to Improve Hospital Performance
Verification of Lean Improvement for Emergency Room Process
Reducing Emergency Department Overcrowding
Inventory Modeling of Perishable Pharmaceuticals
Implementation of an Outpatient Procedure Center
Infectious Disease Control Policy
Balancing Operating Room and Post-Anesthesia Resources
Cost Effectiveness of Colorectal Cancer Screening Test

Areas of Application

Additional Applications

Managing Workforce Resource Actions with Multiple Feedback Control
Analyzing the Impact of Hole-Size on Putting in Golf
Application of Particle Filters in Wildfire Spread Simulation
Predator-Prey Relationship in a Closed Habitat
Intensive Piglet Production Systems
Real-Time Delay Estimation in Call Centers
Pandemic Influenza Preparedness Plans for a Public University

Systems and system environment

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

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. This decision may depend on the purpose of the study

Example:
In the case of a factory system, 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.

Components of a system

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 only be a subset of the overall system for another study

Components of a system

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,

the term **exogenous** is used to describe activities and events in the environment that affect the system.

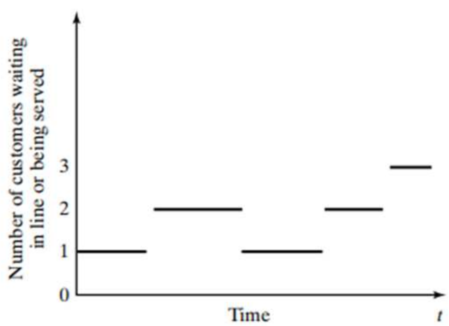
Components of a system

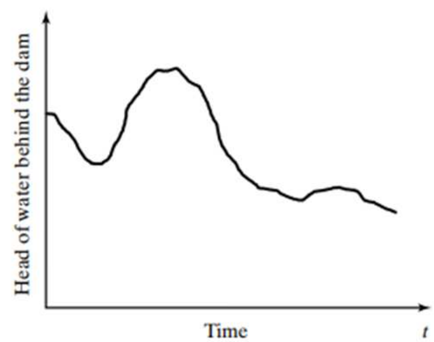
System	*Entities*	*Attributes*	*Activities*	*Events*	*State Variables*
Banking	Customers	Checking-account balance	Making deposits	Arrival; departure	Number of busy tellers; number of customers waiting
Rapid rail	Riders	Origin; destination	Traveling	Arrival at station; arrival at destination	Number of 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

Discrete and Continuous system

A discrete system is one in which the state variable(s) change only at a discrete set of points in time

A continuous system is one in which the state variable(s) change continuously over time.





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/condition
- it is sometimes possible to experiment with the system itself. However, this is not always an option
- A new system might not yet exist; it could be in only hypothetical form or at the design stage
- Even if the system exists, it might be impractical to experiment with it. e.g., . In the case of a bank, reducing the numbers of tellers to study the effect on the length of waiting lines might infuriate the customers so greatly that they will move their accounts to a competitor.

Model of a system

- A model is defined as a representation of a system for the purpose of studying that system.
- For most studies, it is only necessary to consider those aspects of the system that affect 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 model

Mathematical or physical model:
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.

A physical model is a larger or smaller version of an object such as the enlargement of an atom or a scaled-down version of the solar system.

Simulation Models may be classified in different ways:

- **Static or dynamic models**
- **Deterministic or stochastic**
- **Discrete or continuous**

Types of model

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.

Simulation models that contain no random variables are classified as **deterministic**. Deterministic models have a known set of inputs, that will result in a unique set of outputs. e.g. Deterministic arrivals would happen at a Doctor's clinic, if all patients come at the scheduled 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, e.g., at the bank's counter usually customer's interarrival time and service times are random (random input). Output may be average number of people waiting, average waiting time (i.e., statistical estimate)

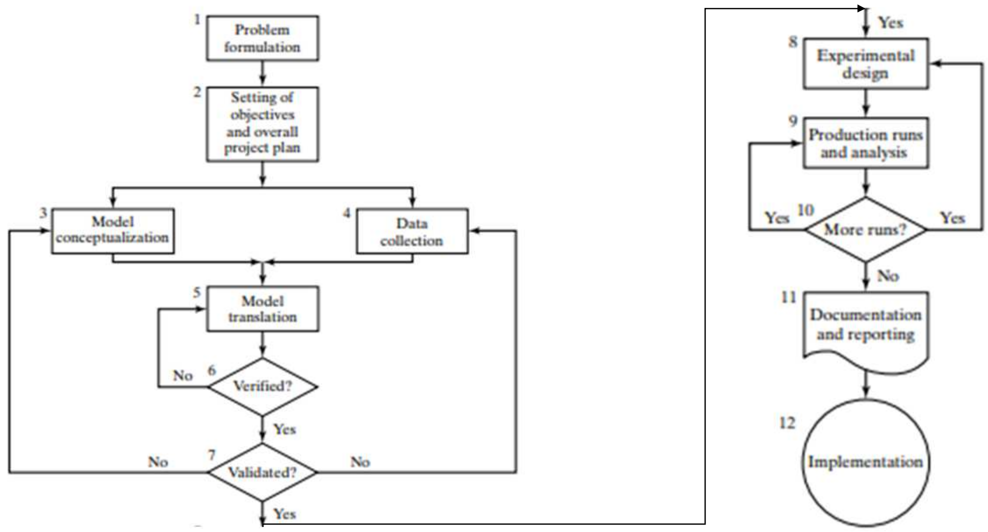
Discrete-event simulation system

In this course, we shall concentrate on **Discrete-event system simulation.**
Discrete-event system 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 rather than analytical methods.

Analytical methods employ the deductive reasoning of mathematics to "solve" the model. For example, differential calculus can be used to compute 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 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

Problem formulation

- Every study should begin with a statement of the problem.
- If the statement is provided by the policymakers 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, the policymakers understand and agree with the formulation.
- There may be a requirement that the the problem be reformulated as the study progresses.

Steps in a simulation study

Setting of objectives and overall project plan

- The objectives indicate the questions to be answered by simulation.
- Determine whether simulation is appropriate
- An alternative systems to be considered and methos for evaluating the effectiveness of these alternatives
- A 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, along with the results expected at the end of each stage

Steps in a simulation study

Model Conceptualization

- it is not possible to provide a set of instructions that will lead to building successful and appropriate models in every instance
- 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.
- It is best to start with a simple model and build toward greater complexity.
- The model complexity need not exceed that required to accomplish the purposes for which the model is intended
- 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.

Steps in a simulation study

Data Collection

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

Steps in a simulation study

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.
- We must decide whether to program the model in a simulation language or to use special-purpose simulation software.
- if the problem is amenable to solution with the simulation software, the model development time is greatly reduced.

Steps in a simulation study

Verification

- Verification pertains to the computer program that has been prepared for the simulation model. Is the computer program performing properly?

Validation

- 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.
- This process is repeated until model accuracy is judged acceptable.

Steps in a simulation study

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 in a simulation study

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.

Steps in a simulation study

Documentation

Two types of documentation. Program documentation and Process documentation

- Program documentation: Can be used again by the same or different analysts to understand how the program operates
- Process documentation: This enable to review the final formulation and alternatives, results of the experiments and the recommended solution to the problem. The final report provides a vehicle of certification.

The results of all the analysis should be reported clearly and concisely in a final report. This will allow the model users (now the decision makers) to review the final formulation, the alternative systems that were addressed, the criteria by which the alternatives were compared, the results of the experiments, and the recommended solution(s) to the problem

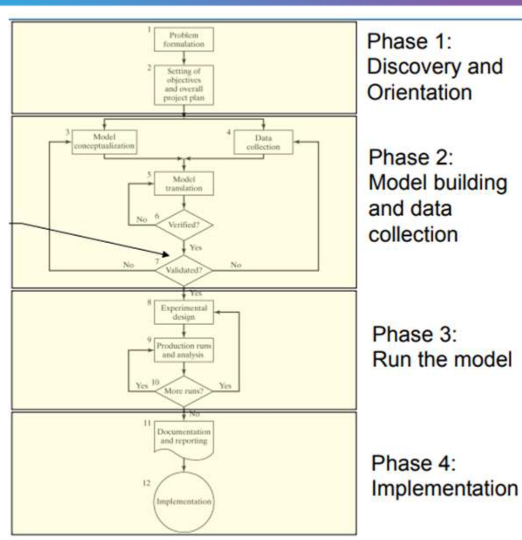
Steps in a simulation study

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 involved during the entire model-building process and if the model user understands the nature of the model and its outputs, the likelihood of a vigorous implementation is enhanced Conversely, if the model and its underlying assumptions have not been properly communicated, implementation will probably suffer, regardless of the simulation model's validity.

Steps in a simulation study



Characterization of Systems

Do it yourself

Name several entities, attributes, activities, events, and state variables for the following systems:

(a) A cafeteria
(b) A grocery store
(c) A laundromat
(d) A fast-food restaurant
(e) A hospital emergency room
(f) A taxicab company with 10 taxis
(g) An automobile assembly line