Simulation & Modeling

Course Code:BIT534CO
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Credit Hours: 3hrs

Unit - 01: Concepts of Simulation

Class Load : 6 hrs

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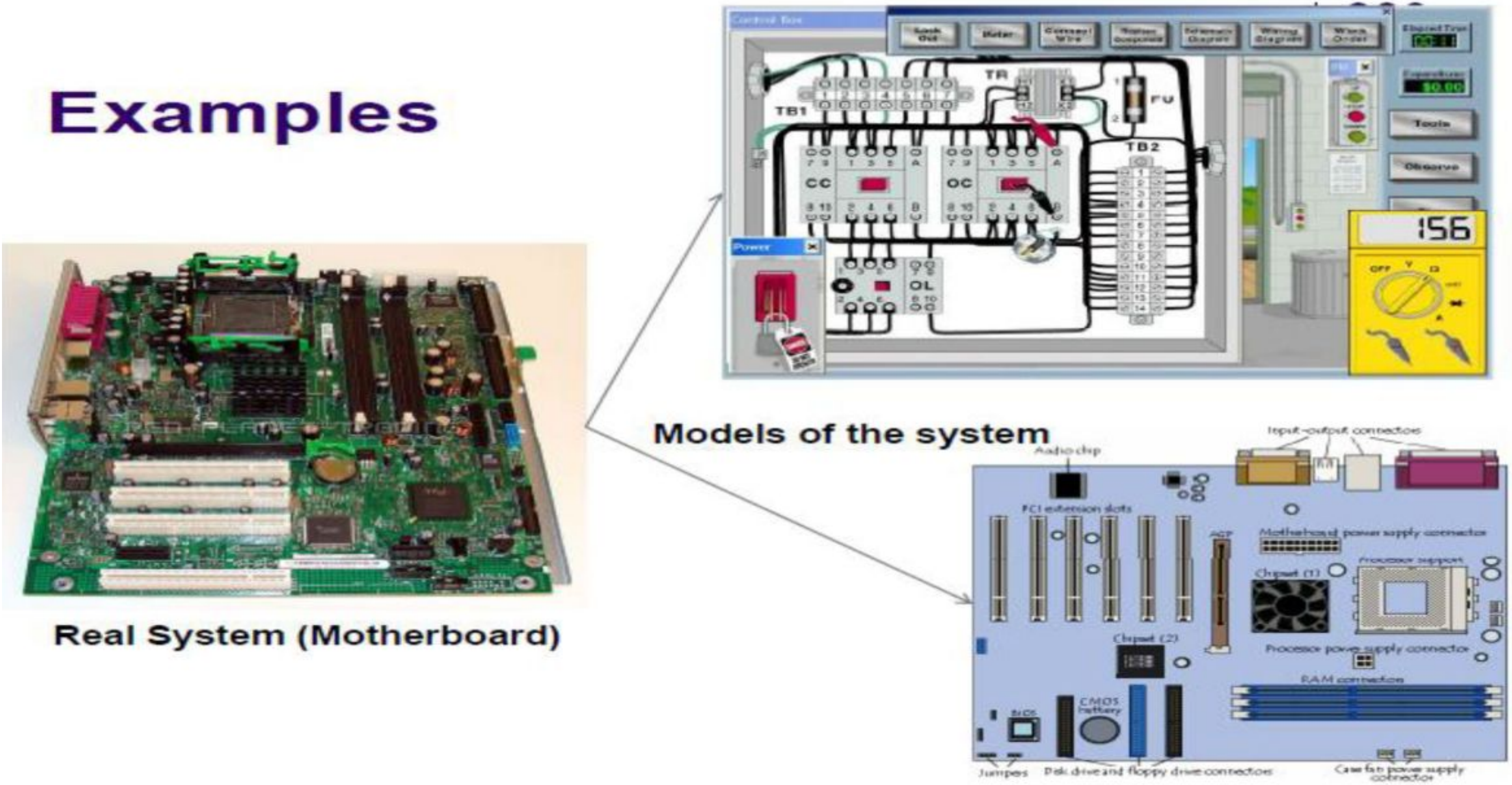
Introduction Session:

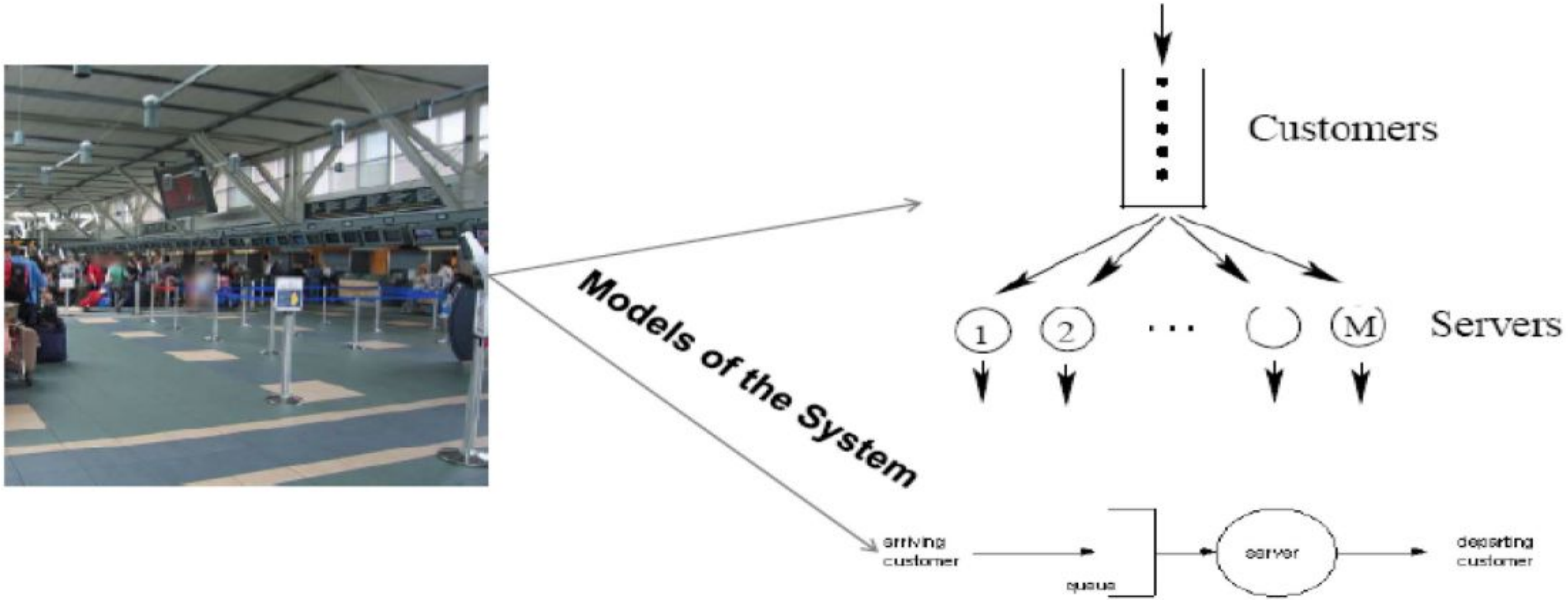
What is Simulation and Modeling?

- A Simulation is the ***imitation*** of the operation of a real-world process or system over time. It is the process of imitating the operations of various kinds of real-world facilities or processes.
- Simulation involves the generation of an **artificial history** of a system and the **observation** of that history to **draw inferences** concerning the operating characteristics of the real world.
- A Model usually takes the form of a **set of assumptions** concerning the operation of the system. The assumptions are expressed in:
  - Mathematical relationships
  - Logical relationships
  - Symbolic relationships between the entities of the system
- The behavior of a system as it evolves over time is studied by developing a **simulation model**. Once a model is developed and validated, it can be used to investigate a wide variety of ***"what-if"*** questions about the real-world system.

Example > Motherboard :



Examples> Airport System :

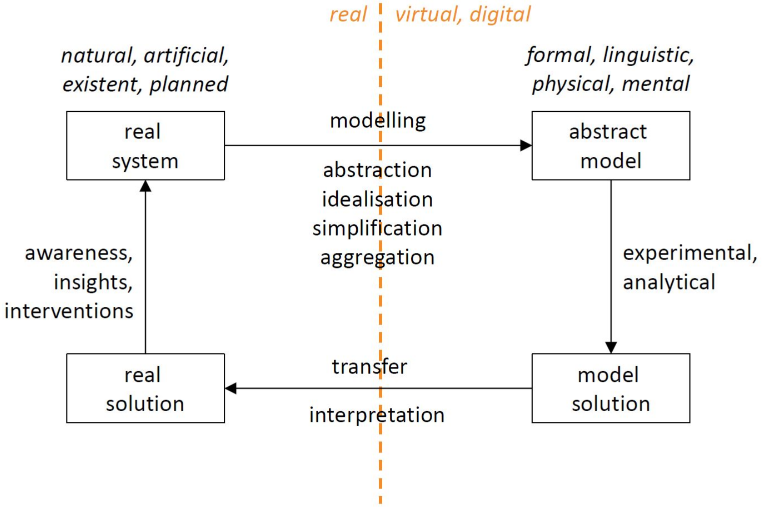


What is Simulation?

- A simulation is the ***imitation*** of the operation of a real-world process or system over time.
- In many cases **we cannot afford finding the right solutions by experimenting with real objects:** building, destroying, making changes may be too expensive, dangerous, or just impossible.

What is Simulation?

- Simulation is **an experimental procedure** for the analysis of real or fictive (imaginative) systems.
- In a simulation, model experiments are performed in order to gain knowledge about the system.
- The execution of a simulation with specific values is called a **simulation experiment**.



What is Simulation?

- Simulation is the **numerical technique** for conducting experiments on **digital computer**, which involves logical and mathematical relationships that interact to describe the behaviour and the structure of a **complex real world system** over extended period of time.
- In simple term, **Simulation and Modelling is a substitute for the physical experiment**, in which computers compute the results of some physical phenomenon.

Goal of Simulation and Modelling:

- A model can be used to investigate a wide variety of **"what if"** questions about real-world system.
  - Potential changes to the system can be simulated and predict their impact on the system.
  - Find adequate parameters before implementation.
- So simulation can be used as :
  - Design tool to predict the performance of new system
  - Analysis tool for predicting the effect of changes

It is better to do simulation before Implementation.

Why Simulation?

- Investigations on the real system are **too complex, expensive, ethically incorrect** or dangerous.
- Real systems does not (yet) exist. *Eg: Vacuum-Pressure System*
- Real systems cannot be observed directly.
- Experiments using a model can be modified more easily than the real system. *Eg: Climate Modeling*
- Reproducibility of experiments.
- Real system is not understood or very complex. *Eg: Engineering Design*
- Might be used for education.

When Simulation is the Appropriate Tool?

- Simulation **enables** the study and experimentation with the **internal interactions** of a complex system, or of a **sub-system** within a complex system.
- Informational, organizational and environmental **changes** can be simulated and the effect of those **alterations** on the model's behavior can be **observed**.
- The **knowledge gained** in designing a simulation model can be of great value toward suggesting **improvement** in the system under investigation.
- By changing simulation inputs and observing the resulting outputs, **valuable insight may be obtained** into which variables are most important and how variables interact.

When Simulation **is** the Appropriate Tool?

- Simulation can be used to experiment with **new designs or policies** prior to implementation, so as to prepare for what may happen.
- Simulation can be used to **verify analytic solutions** (mathematical solutions).
- By simulating different capabilities for a machine, **requirements can be determined**.
- The modern system (factory, water fabrication plant, service organization, etc.) is so complex that the **interactions can be treated only through simulation.**

When Simulation is **not** Appropriate?

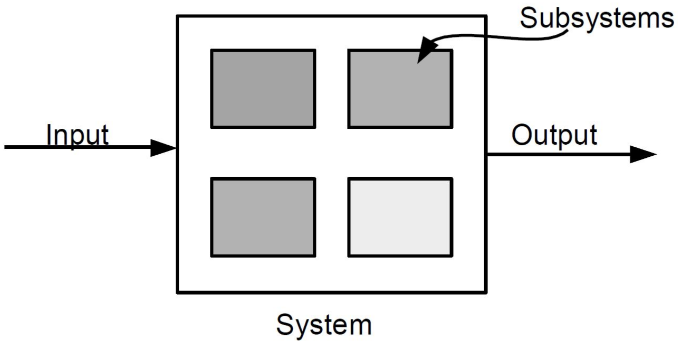
- Simulation should only be used when the problem **cannot be** solved using common sense.
- If the problem can be **solved analytically,** simulation is unnecessary.
- **Direct experimentation** is preferable if it's easier to perform than simulating.
- Avoid simulation if the **costs outweigh** the benefits.
- Do not simulate if you **lack** the resources or time.
- Simulation is not advised when **no data is available**—not even rough estimates.
- Lack of time or unavailable personnel makes simulation impractical.
- **Overestimated expectations** or **pressure from managers** for fast results can make simulation unsuitable.
- If the system's behavior is **too complex or undefinable**, simulation is not appropriate.

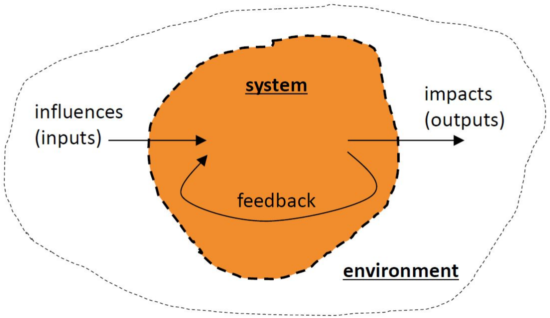
System:

- The term system is derived from the Greek word **Systema**, which means an organized relationship among **functioning units** or components units or components.
- System exists because it is designed to **achieve one or more objectives.**
- We come into daily contact with the **transportation system**, the **telephone system**, the **accounting system**, the **production system**, and for two decades the computer system.
- There are more than a hundred definitions of the word system, but most seem to have a common thread that suggests that a system is an **orderly grouping of interdependent components** linked together according to a plan to achieve a specific objective.

System:

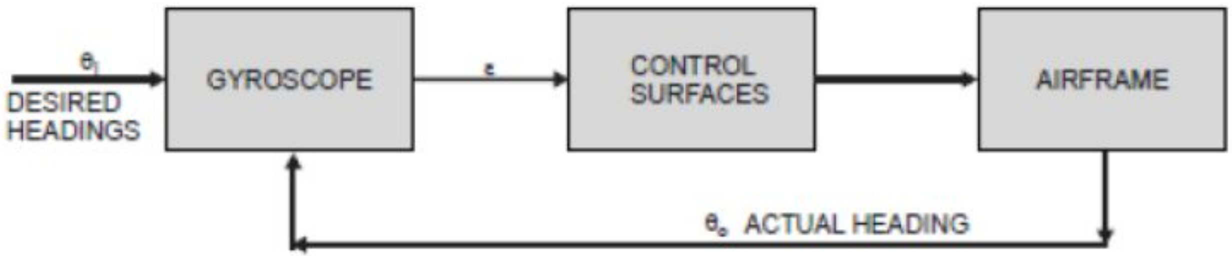
- The study of the systems concepts, then, has **three basic implications**:
  - A system must be designed to achieve a **predetermined objective**.
  - **Interrelationships** and **interdependence** must exist among the components.
  - The objectives of the organization as a whole have a **higher priority** than the objectives of its subsystems.





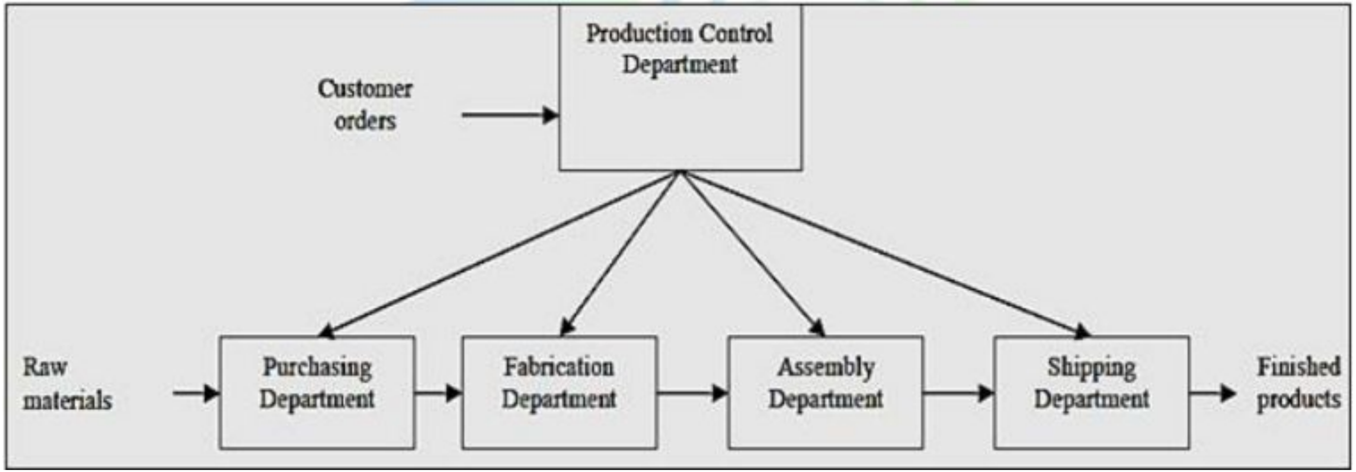
Example of a System:

- 1. Aircraft flying under the **control of an autopilot**



- A **gyroscope** in the autopilot aircraft **detects the difference** between the **actual and desired heading**. It sends a signal, to move, to the **control system.** In response to control system the **airframe steers** towards the desired heading.

A Factory System:



Major Components of System are **Fabrication Department** that **makes parts** and the **Assembly Department** **assembling the parts**.

A **purchasing department** maintains the supply of raw materials and a **shipping department** dispatches the finished product. A **production control** receive orders and assign work to other departments.

Components of a System:

- **Entity:** An entity is an object of interest in a system. Example: In the factory system, departments, orders, parts, and products are the entities.
- **Attribute:** An attribute denotes the property of an entity. Example: Quantities for each order, type of part, or several machines in a Department are attributes of the factory system.
- **Activity:** Any process causing changes in a system is called an activity. Example: Manufacturing process of the department.
  - **Exogenous Activity:** Activity occurring in the environment.
  - **Endogenous Activity:** Activity occurring within the system.

Components of a System:

- **State of the System:**
  - The state of a system is defined as the collection of variables necessary to **describe a system at any time**, relative to the objective of study. In other words, the state of the system means a description of all the entities, attributes and activities as they exist at one point in time.
  - In other words, state of the system mean a **description of all entities, attributes and activities** as they exist at one point in time.
- **Event:** An event is defined as an instantaneous **occurrence of any activity** that may change the state of the system.

Components of a System:

System	Entities	Attributes	Activities	Events	State Variables
Bank	Customers	Balance, Credit Status	Depositing, Withdrawal	Arrival, Departure	No of busy tellers, No. of Customers
Production	Machine	Speed, Capacity	Welding, Stamping	Breakdown	Status of machine (busy, idle or down)
Communication	Messages	Length, Destination	Transmitting	Arrival at Destination	Number waiting to be transmitted.

Components of a System > Examples :

Banking system

- **Objective**: Measure wait time of customers
- **Entity** – Customers
- **Attribute** – Entry time, Transaction type, Exit time
- **Activity** – Transaction
- **State** – Customers in the bank
- **Event** – Arrival, Departure of customers

Banking System

- **Objective** – Measure deposits and withdrawals
- **Entity** – Customers
- **Attribute** – transaction type, Amount deposited or withdrawn
- **Activity** – Transaction
- **State** – Volume of cash in the bank
- **Event** – Act of transaction

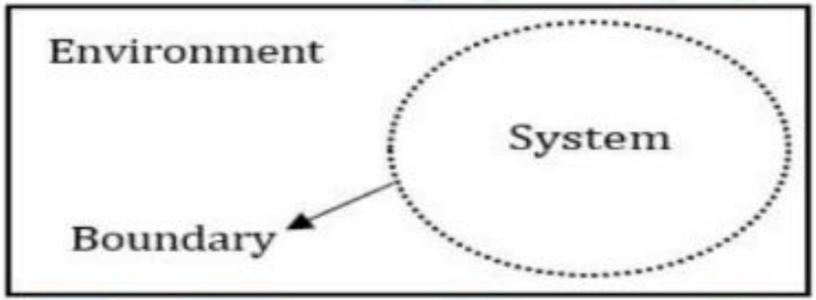
Petrol Station

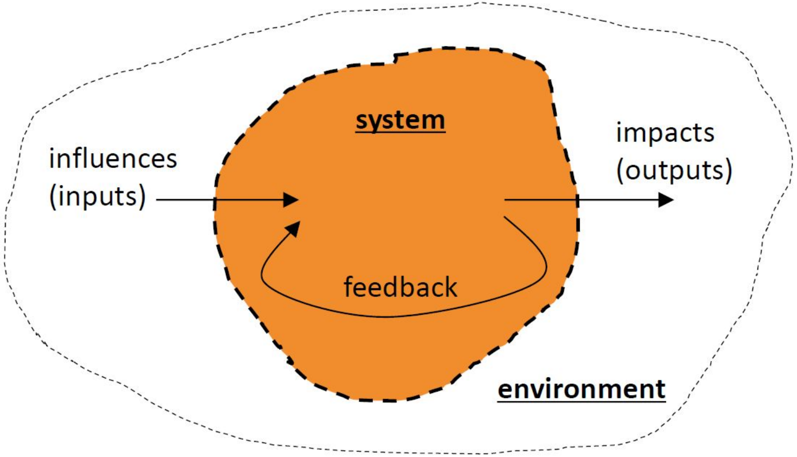
- **Objective** – Measure in and out flow of fuel
- **Entity** – Vehicle
- **Attribute** – vehicle Volume, consumed fuel by vehicle
- **Activity** – Filling fuel
- **State** – Volume of fuel
- **Event** – Buying fuel

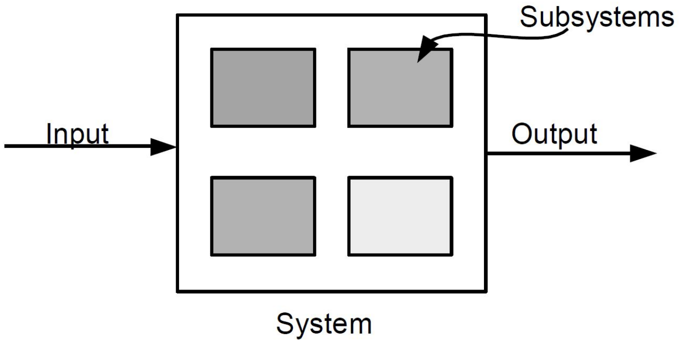
System Environment:

- Everything that **remains outside of the system** under Consideration is called **system environment**. The system is often **affected by change** occurring outside the environment.
- When we are going to model the system, we must **decide the boundary** between the system and the environment. This decision depends on the **purpose** of the system study.
  - **Small System Boundary** may not include necessary components.
  - **Larger System Boundary** may have high degree of error propagation and management difficulties.
- In the case of the **factory system,** factors controlling the arrival of the order may be considered to be the influence of the factory (i.e. part of the environment).

▶ System Environment:







System Types:

- **Closed System:**
  - If any system shows **endogenous activity** then the system is said to be a closed system. A closed system is one where there is **no interaction** between the environment and the system components. **E.g.: Water in an insulated flask.**

- **Open System:**
  - If any system shows **exogenous activity** then the system is said to be an open system. The term exogenous is used to describe the activity in the environment **that affects** the system. **E.g : Bank system.**

System Activity:

- **Endogenous Vs. Exogenous Activity**
- **Endogenous Activity:**
    - Endogenous Activity occurs within a system.
    - Therefore, a system displaying endogenous activity is called a closed system.
- **Exogenous Activity:**
    - Exogenous Activity occurs in an environment that affects the system.
    - Therefore, a system displaying exogenous activity is called an open system.

System Activity:

- ❖ **Deterministic Vs. Stochastic Activity**
- ❖ **Deterministic Activity:**
  - ➢ Deterministic Activity can be described in terms of its input using mathematical functions or formulae.
  - ➢ **Example:** Arrival of patients to the Dentist at a scheduled time.
- ❖ **Stochastic Activity:**
  - ➢ Stochastic Activity varies over possible outcomes and **cannot be predicted** using mathematical functions.
  - ➢ The randomness of stochastic activity is part of the system environment and can be measured and described in a **probability distribution**.
  - ➢ **Example:** random arrival and service time at banks.

Discrete and Continuous System:

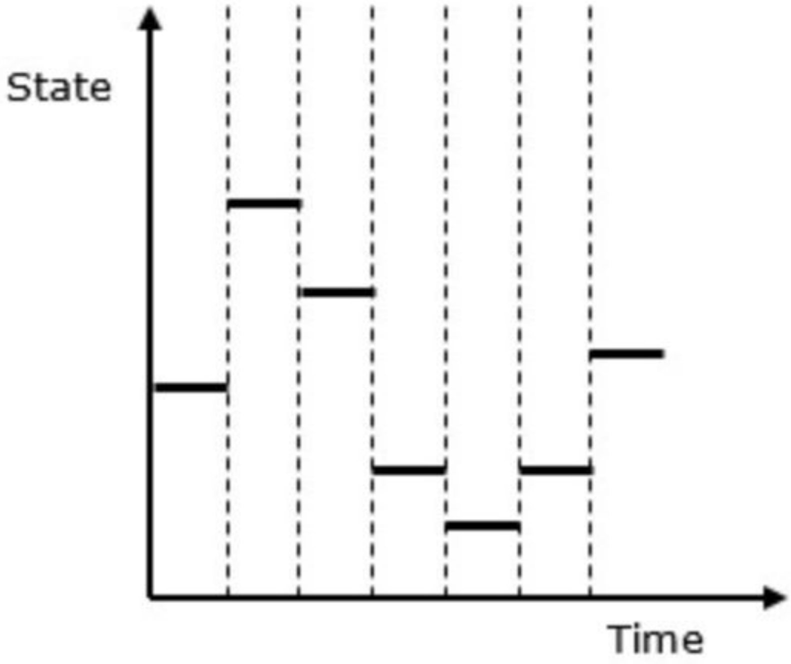
- **Discrete System**
  - In discrete systems, **the changes in the system state are discontinuous** and each change in the state of the system is called an event.
  - A discrete system is one in which the state variables changes **instantaneously** (immediately) at **separate point of time**.
  - These systems rely on **quantized or digital representations**, where the variables can only take on specific discrete values.
  - Key characteristics of discrete systems include:
    - Variables take on discrete values (e.g., 0 or 1)
    - Behavior changes at specific points or intervals
    - Digital representation (e.g., computer hardware, digital display)
    - Quantized values or Step Values (e.g., integer values)

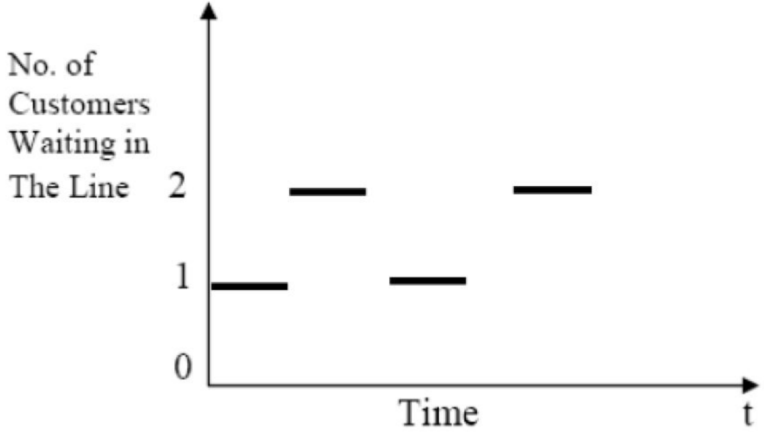
Discrete and Continuous System:

- **Discrete System**
  - **Example:** Bank System
    - The bank is an example of a discrete system: 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 shows how the number of customers changes only at discrete points in time.

Discrete and Continuous System:

- **Discrete System**





Discrete and Continuous System:

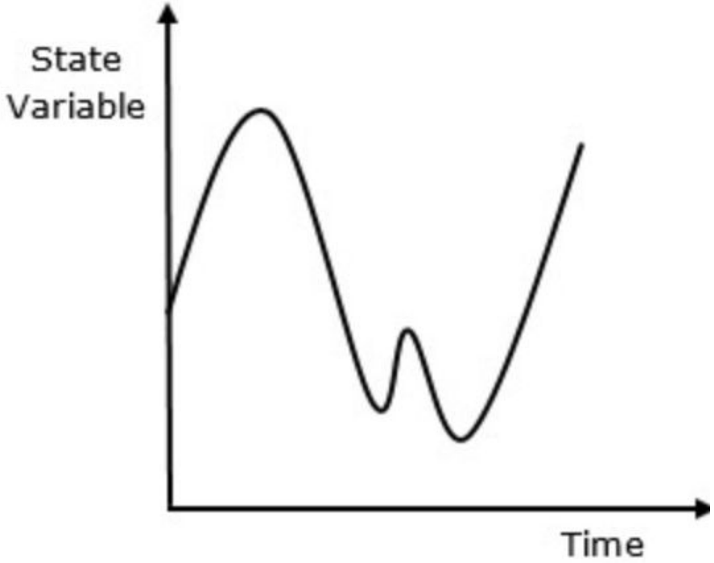
- **Continuous System**
  - A continuous system is one in which the **state variable(s) change continuously over time**.
  - **Analog or continuous signals** are used, allowing for smooth transitions and continuous changes.
  - Key characteristics of continuous systems include:
    - Variables can take on any value within a certain range.
    - Behavior can be represented by continuous representations.
    - Analog representation (e.g., electrical circuits, fluid dynamics).
    - Continuous values (e.g., real numbers).

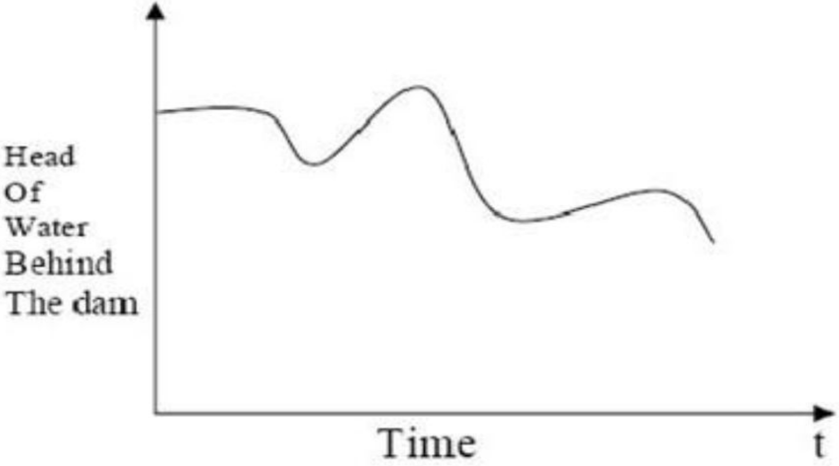
Discrete and Continuous System:

- **Continuous System**
  - **Example: Head of Water behind the Dam**
    - During winter seasons level of which water decreases gradually and during rainy season level of water increase gradually. The change in water level is continuous. The figure below shows the change of water level over time.

Discrete and Continuous System:

- **Continuous System**





Real Time Simulation:

- Real-time simulation is a powerful technique that combines **actual physical devices** with **computer simulation** to create a hybrid testing environment. Instead of building complete mathematical models from **scratch**, this approach uses real hardware components alongside computer-simulated parts. **Example:-**Power Grid Simulation, Aircraft Simulation.

- **Why Use Real-time Simulation?**
  - **Traditional Mathematical Modeling Challenges:**
    - Requires deep understanding of physical and chemical laws
    - Involves extensive experiments and measurements
    - Time-consuming coefficient derivation
    - Complex when non-linear systems are involved

Real Time Simulation

- **Real-time Simulation Advantages:**
  - **Saves Time:** Avoids lengthy preliminary modeling work
  - **Uses Real Hardware:** Incorporates actual system components
  - **Human Interaction:** Can include human operators without modeling human behavior
  - **Immediate Response:** Operates in real-time with physical devices

- **How Does Real-time Simulation Work?**
  - Real-time simulation systems must:
    - **Respond Immediately** to signals from physical devices.
    - Send Signals at **precise time intervals**
    - Operate in Real-time (no delays that would affect the physical system)
    - Interface between digital/hybrid computers and physical hardware

Real Time Simulation

- **Applications:**
  - **Aerospace Industry**
    - Real-time simulation is extensively used in aerospace for **flight control system development**, m**ission rehearsal**, and **fault testing.**
  - **Training Simulators**
    - Simulators recreate physical and sensory environments to **train human operators**, especially when real environments are inaccessible or hazardous.
    - Examples:
      - **Flight Simulators:** Give pilots the experience of controlling an actual aircraft
      - **Space Training:** Astronauts trained using spring harness systems that simulated lunar gravity (reduced apparent weight to match moon conditions)

Real Time Simulation

- **Applications:**
  - **Automotive Systems Testing**
    - Automotive companies employ real-time simulation for **autonomous vehicle development**, **ADAS testing**, and **vehicle dynamics validation**.
    - **Example:** Tesla and other automakers simulate road conditions, pedestrian behavior, and traffic environments to test self-driving algorithms in real time without physical risk.
  - **Human-in-the-Loop (HIL) Simulation**
    - Real-time simulation allows humans to interact with systems being developed or tested, especially where **modeling human behavior mathematically is infeasible.**
  - **Power System Simulation**
    - Used for **grid stability analysis**, **smart grid testing**, and control strategy development in power engineering.

Model of System (System Modeling):

- A model is defined as a **representation of a system for the purpose of studying the system.**
- The model is similar to a real system, which helps the analyst predict the effect of changes to the system.
- It is necessary to **consider only those aspects** of the system that affect the problem under investigation.
- The aspect of system that affect the problem under investigation, are represented in a model of the system.
- Therefore model is the **simplification of the real system**.

Principles used in Modelling:

- There is **no unique model** of a system. Different models of the same system will be produced by different system analysts who are interested in different aspect of system.
  - **1. Block-building:** The description of system should be organized as **a sequence of blocks**. It simplifies the interaction between block within system. E.g. the block of factory system.
  - **2. Relevance:** The model should only include relevant information. Irrelevant information should not include because it increases the complexity of model and takes more time and effort to solve model.
  - **3. Accuracy:** The gathered information should be accurate as well. For example in aircraft system the accuracy as movement of the aircraft depends upon the representations of airframe such as a rigid body.
  - **4. Aggregation:** It should be considered that to which numbers of individual entities can be grouped into a block. For example in factory system, **different department are grouped together handled by production manager.**

Types of System Model/Models:

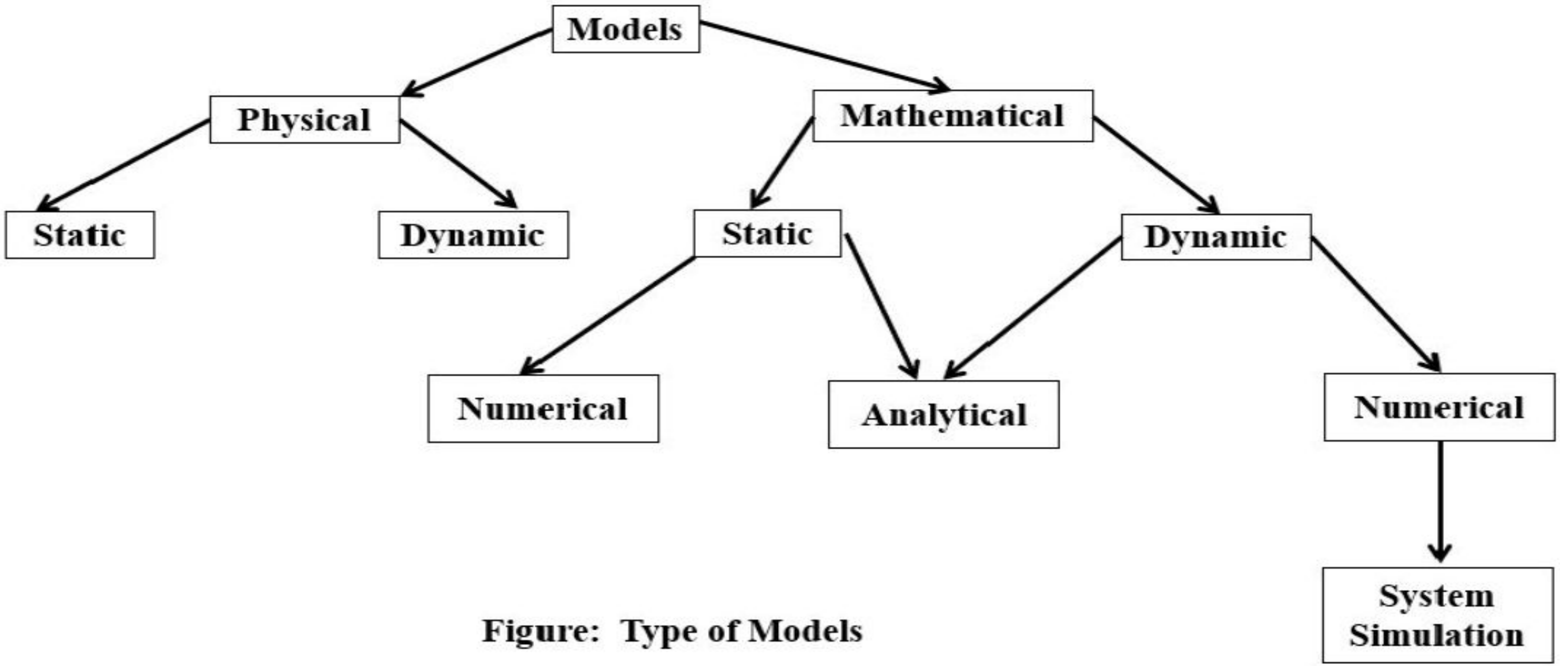


Figure: Type of Models

Types of Model:

- **Physical Model**
  - Physical model is the smaller or larger physical copy of an object being modelled.
  - The geometry of model is just the rescaled view of the object it represents.
  - **Example:** Enlargement of an atom or a scaled-down version of the **solar system**.

- **Mathematical Model**
  - Uses symbolic notation and the mathematical equations to represent a system. Attributes are represented by variables and the activities are represented by mathematical function.
  - **Example:** $f(x) = mx + c$ is a mathematical model of a line.
  - Such model is also called an abstract model.

Types of Model:

❖ **Static Model**

➢ The static model addresses the static structural view of a problem, which **does not vary with time** or where time is not a significant variable.

➢ **Example:** Scientist has used models in which sphere represents **atom**.

❖ **Dynamic Model**

➢ Dynamic simulation models represent systems as they **change over time**. Includes models which are affected with time.

➢ **Example:** The simulation of a bank from 10:00 am to 4:00 pm is an example of a dynamic simulation.

➢ The mechanical and electrical systems are the example of dynamic system.

Types of Model:

- **Deterministic Model**
  - It contains no random variables. They have a known set of inputs which will result in a unique set of outputs.
  - **Example:** Arrival of patients to the Dentist at the scheduled appointment time.

- **Stochastic Model**
  - Has one or more random variable as inputs. Random inputs leads to random outputs.
  - **Example:** Simulation of a bank involves random inter-arrival and service times.

Types of Model:

- **Analytical Model**
  - Applying analytical techniques means using the **deductive reasoning of mathematical theory** to solve a model. In Practice, only certain forms of equations can be solved.
  - Analytical solutions are exact and can be obtained using mathematical formulas.
  - **Example:** Solving differential equations, find integrals

- **Numerical Model**
  - Numerical methods involves applying **conceptual/numerical procedures** to solve equations.
  - Numerical solutions are approximate and are obtained by using numerical methods.
  - E.g.: Finding roots of polynomial, solving a system of linear equations.

Types of Model:

- **Static Physical model**
  - Static physical model is the physical model which describes **relationships that do not change with respect to time.**
  - Such models can be used **to study the attributes of a system** at a single point in time where the object property or attributes will not change over time.
  - Example: In the course of designing aircraft and ships and testing in wind tunnels and water tanks.
- **Dynamic Physical Model**
  - Dynamic physical models can be used **to study the behavior of a system over time.**
  - These models rely on an analogy between the system being studied and some other system of a different nature.
  - This analogy is usually based on the underlying similarities in the forces that govern the behavior of the two systems.

▶ Types of Model:

❖ **Static mathematical model:**

❖ Static mathematical model is the mathematical model that represents the logical view of the system in equilibrium (balance) state.

❖ Such models are time-invariant (does not depend on the absolute time).

❖ It is generally represented by the basic algebraic equations.

❖ E.g.: An equation relating the length and weight on each side of a playground variation supply and demand relationship model of a market and so on

If mathematical model doesn't involve time i.e. system does not change with time, it is called static mathematical model of the system.

Types of Model:

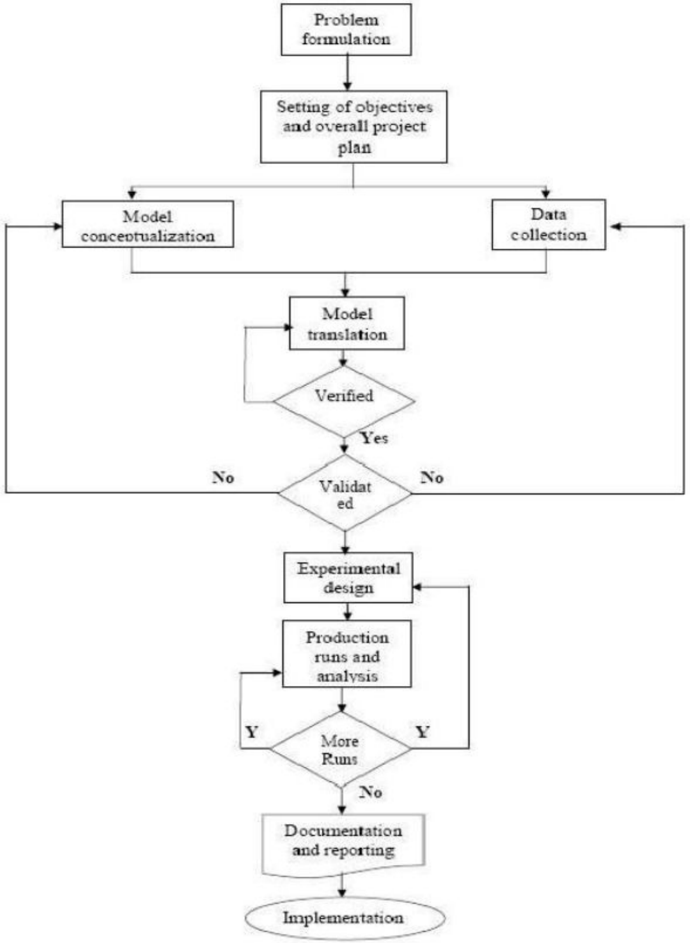
- **Dynamic mathematical model:**
  - Dynamic mathematical model is the mathematical model that accounts for the time dependent changes in the logical state of the system.
  - Such models are time-variant (output dynamically changes over time).
  - It is generally represented by differential equations or difference equations.
  - E.g.: a model of a car suspension, a model of a traffic system.

Three Model Levels:

- **Conceptual**
  - Very high level
  - How comprehensive should the model be? What to include, what to exclude...
  - What are the state variables, which are dynamic, and which are important?
- **Specification**
  - On paper
  - May involve equations, pseudocode, etc.
  - How will the model receive input?
- **Computational**
  - A computer program
  - General-purpose PL or simulation language?

▶ Steps in Simulation Study:

1. Problem Formulation
2. Setting of objectives and overall project plan
3. Model Conceptualization
4. Data Collection
5. Model Translation
6. Verified
7. Validated
8. Experimental Design
9. Production Runs and Analysis
10. More Runs
11. Documentation and Reporting
12. Implementation



Steps in Simulation Study:

1. **Problem formulation:**
   - ➢ Every study begins with a **statement of the problem**, provided by **policy makers**. Analyst ensures its clearly understood. If it is developed by analyst, policy makers should understand and agree with it.
2. **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. The overall project plan should include:
     - A statement of the **alternative** systems.
     - A method for evaluating the **effectiveness** of these alternatives.
     - Plans for the study in terms of the number of people involved.
     - Cost of the study
     - The **number of days required** to accomplish each phase of the work with the anticipated results.

Steps in Simulation Study:

3. **Model conceptualization:**

   - 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. Model conceptualization enhances the quality of the resulting model and increase the confidence of the model user in the application of the model.

4. **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.

Steps in Simulation Study:

5. **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**.
   - It can be programmed by using **simulation languages** or special purpose simulation **software**. Simulation languages are powerful and flexible. Simulation software models development time can be reduced.
6. **Verified:** It **relates** to the computer program prepared for simulation model and **checking** the performance. If the input parameters and logical structure are **correctly represented**, verification is completed. It answers the question **"Are we building the model right?"**
7. **Validated:** It is the determination that a model is an **accurate representation** of the real system. Achieved through **calibration of the model**, an iterative process of **comparing** the model to actual system behavior and the **discrepancies** between the two. It answers the question **"Are we building the right model ?"**

Steps in Simulation Study:

8. **Experimental Design:** The **alternatives** that are to be simulated must be determined. Which alternatives to simulate may be a function of runs. For each system design, decisions need to be made concerning:
   - Length of the initialization period
   - Length of simulation runs
   - Number of replication to be made of each run
9. **Production runs and analysis:**
   - They are used to **estimate measures of performance** for the system designs that are being simulated.
10. **More runs:**
    - Based on the analysis of runs that have been completed, the analyst determines **if additional runs are needed** and what design those additional experiments should follow.

▶ Steps in Simulation Study:

11. **Documentation and Reporting:** **Two types** of documentation: Program documentation and Process documentation.

    - ➢ **Program documentation:** It can be used by the same or different analysts to understand **how the program operates**.
    - ➢ **Process documentation:** It gives the **history of a simulation project**. The result of all analysis should be reported clearly and concisely in a final report. This enables to review the **final formulation** and **alternatives**, **results** of the experiments and the **recommended** solution to the problem.

12. **Implementation:** The success of the implementation phase **depends** on how well the previous eleven steps have been performed. It is also **contingent (depends)** upon how thoroughly the analyst has involved the ultimate model user during the entire simulation process. If the model user has been thoroughly **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 implementation is enhanced.

Phases of a Simulation Study:

- **I Phase**
  - Consists of **steps 1 and 2 (Problem Formulation, Setting of Objective and overall design)**
  - It is period of discovery/orientation.
  - The analyst may have to restart the process if it is not fine-tuned.
  - Recalibrations and clarifications may occur in this phase or another phase.
- **II Phase**
  - Consists of steps **3, 4, 5, 6 and 7 (Model Conceptualization, Data Collection, Model Translation, Verification, Validation)**
  - Is related to Model building and data collection.
  - A continuing interplay is required among the steps.

Phases of a Simulation Study:

- **III Phase**
  - Consists of **steps 8, 9 and 10 (Experimental Design, Production Runs and Analysis, Additional Runs)**
  - Involves running the process.
  - Conceives a thorough plan for experimenting.
  - The output variables are estimates that contain random error and therefore proper statistical analysis is required.
- **IV Phase**
  - Consists of **steps 11 and 12 (Documentation and Reporting, Implementation)**
  - Successful implementation depends on the involvement of user and every steps successful completion.

Phases of a Simulation Study (Summary):

The simulation model building can be broken into 4 phases

- **I Phase**
  - Consists of steps 1 and 2
  - It is period of discovery/orientation
  - The analyst may have to restart the process if it is not fine-tuned
  - Recalibrations and clarifications may occur in this phase or another phase.
- **II Phase**
  - Consists of steps 3,4,5,6 and 7
  - A continuing interplay is required among the steps
  - Exclusion of model user results in implications during implementation
- **III Phase**
  - Consists of steps 8,9 and 10
  - Conceives a thorough plan for experimenting
  - Discrete-event stochastic is a statistical experiment
  - The output variables are estimates that contain random error and therefore proper statistical analysis is required.
- **IV Phase**
  - Consists of steps 11 and 12
  - Successful implementation depends on the involvement of user and every steps successful completion.

Advantages of Simulation:

- New policies, procedures, decision rules, and information flows can be **explored** without disrupting actual system operations.
- New hardware designs, physical layouts, or transportation systems can be **tested** before investing in them.
- Hypotheses about the causes of certain phenomena can be tested for feasibility.
- Time can be **accelerated or slowed** to examine processes more effectively.
- Insight can be gained into how different **variables interact**.
- The importance of **specific variables** to system performance can be better understood.
- **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 of Simulation:

- Model building requires **special training**. It is an art that is learned over time and through experience.
- Simulation results can be **difficult to interpret**. Most simulation outputs are essentially **random variables**, so it can be hard to distinguish whether an observation is a result of system interrelationships or of randomness.
- 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.
- Simulation is used in some cases when an analytical solution is **possible** or even preferable.

Areas of Application:

- **Manufacturing Applications**
  - Dynamic modeling of **continuous manufacturing systems**, using analogies to electrical systems
  - Modeling for quality and productivity in **steel cord manufacturing**
  - Shared resource capacity analysis in **biotech manufacturing**
  - Neutral information model for simulating **machine shop operations**
- **Construction Engineering and Project Management**
  - Impact of **multitasking** and **merge bias** on procurement of complex equipment
  - Application of lean concepts and simulation for **drainage operations maintenance** crews
  - Building a virtual shop model for **steel fabrication**
  - Simulation of the **residential lumber supply chain**

Areas of Application:

- **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 **non-war fighting operations.**
  - Multi Trajectory performance for **varying scenario sizes.**
- **Semiconductor Manufacturing**
  - Comparison of dispatching rules using **large-facility models.**
  - Assessment of potential gains in productivity due to **proactive retired management.**
  - Comparison of a 200 mm and 300 mm **X-ray lithography cell.**

Areas of Application:

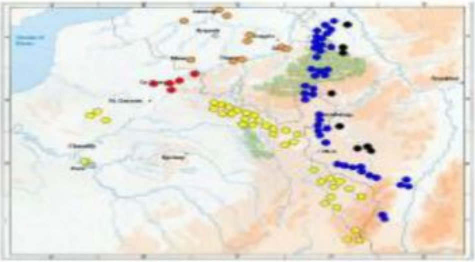
- **Human Systems**
  - Modeling **human performance** in complex systems.
  - Studying the human element in **air traffic control**.
- **Logistics, Transportation and Distribution Applications**
  - Evaluating the potential benefits of a **rail-traffic planning algorithm.**
  - Evaluating strategies to improve **railroad performance.**
  - Analysis of passenger flows in an **airport terminal.**
  - Logistic issues in autonomous **food production systems** for extended duration space exploration.
  - Production distribution in **newspaper industry**

Areas of Application:

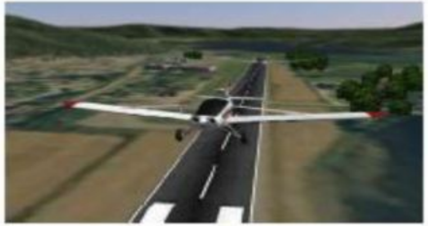
- **Business Process Simulation**
  - Impact of connection bank redesign on **airport gate assignment.**
  - **Product development** program planning.
  - **Reconciliation (Compatibility)** of business and system modeling.
  - Personal **forecasting** and strategic workforce planning.
  - Optimization of a **telecommunications billing system**
- **Health Care**
  - 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

Areas of Application:

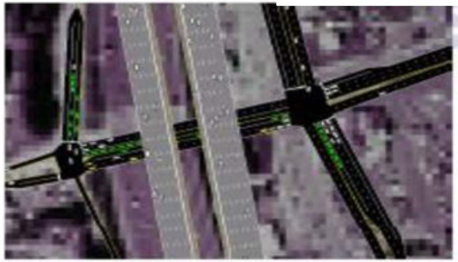
A few more applications ...



War gaming: test strategies; training



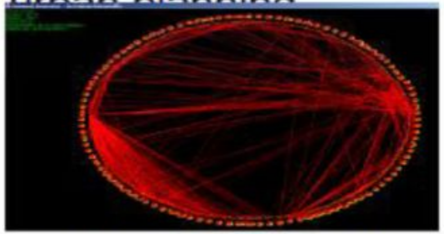
Flight Simulator



Transportation systems: improved operations; urban planning

Parallel computer systems: developing scalable software

Games



Computer communication network: protocol design

PYQs:

1. Define Simulation. Discuss when it is used and various steps used in simulation study. **2025 PU (12)**
2. What are the different phases of a comprehensive simulation study? Explain the tasks that each phase encompasses. **2024 PU (12)**
3. What are continuous and discrete systems and what types of systems they represent? Give Examples. **2024 PU (8)**
4. What is continuous system simulation? Describe discrete system simulation. What is hybrid simulation? Briefly discuss. **2025 PU (8)**
5. List any 5 situations when simulation is appropriate tool and when it is not. **2025 PU (8), 2024 PU (8)**
6. Write down the applications of real-time simulations. **2024 PU (6)**
7. Short Notes:
    a. Hybrid Simulation **2024 PU (4)**

References:

1. Jerry Banks, John S. Carson II, Barry L. Nelson, David M. Nicol – *Discrete-Event System Simulation* – Pearson (2013)
2. Averill M. Law – *Simulation Modeling and Analysis* – McGraw-Hill Education (2014)
3. Geoffrey Gordon – *System Simulation*

THANKS!

Do you have any questions?

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