Chapter 1
Introduction to Simulation

System, Model and Simulation

System

- The term system is derive from the Greek word systema, which means an organized relationship among functioning units or components units or components.
- A system is defined as an aggregation of objects or components joined in some regular interaction or interdependence.
- Systems are designed to achieve one or more objectives.
- Interrelationship and interdependence must exists among the system components.
- The objectives of the organization as a whole have a higher priority than the objectives of its subsystems.

Model

- A model is a simplified representation of a system at some particular point in time or space intended to some particular point in time or space intended to promote understanding of the real system.

- Model is a conceptual framework that describes the system.
- Modelling is the process of representing a model which includes its construction and working. This model is similar to a real system, which helps the analyst predict the effect of changes to the system.

Simulation

- The representation of the behavior or characteristics of one system through the use of another system, specially a computer program designed for the purpose.
- It is a program that mimics (imitate) the behavior of the real system of the real system.
- Simulation is the representation of a real life system by another system, which depicts the important characteristics of the real system and allows experimentation on it.
- A model construct a conceptual framework that describes a system. The behavior of a system that evolves over time is studied by developing a simulation model.

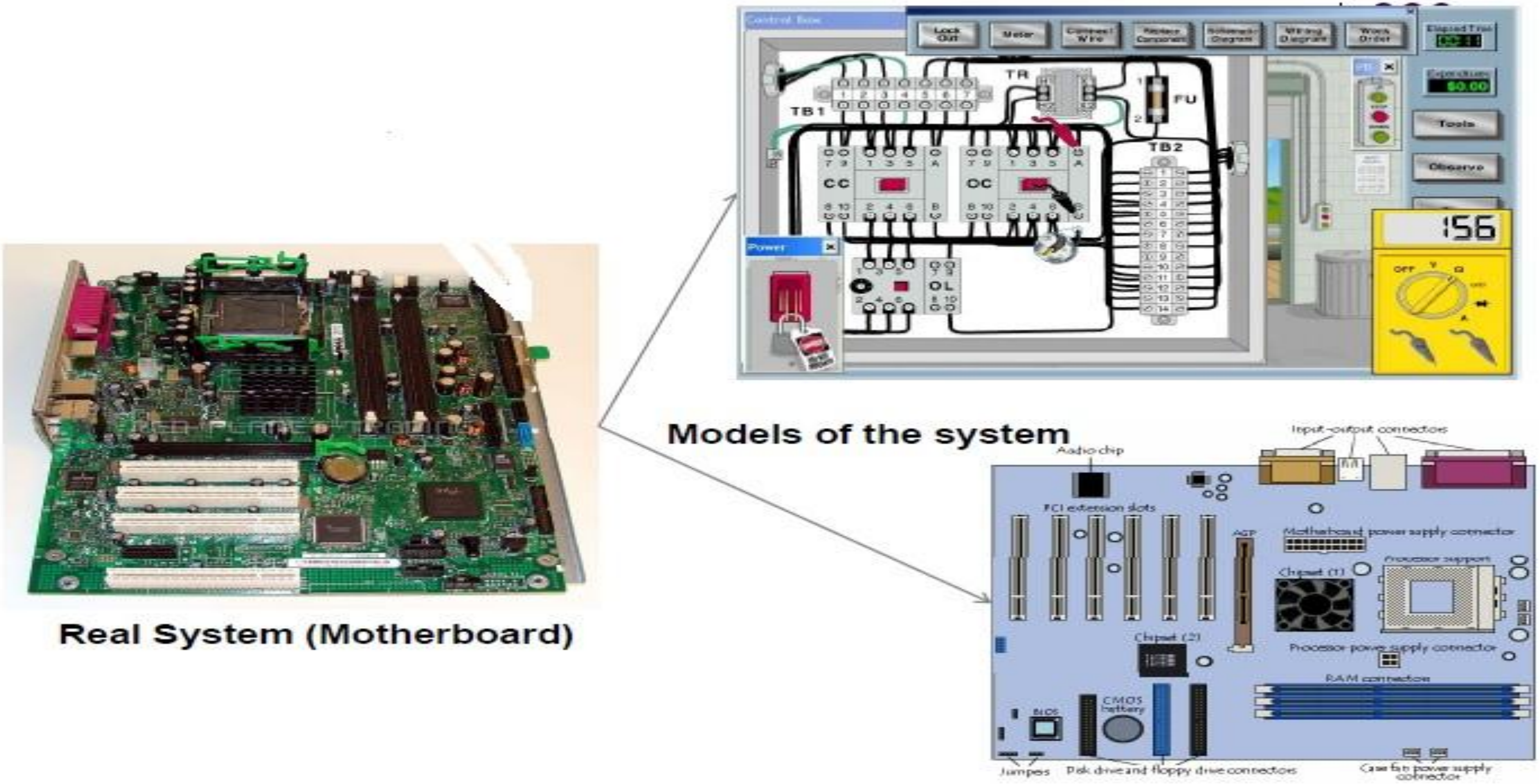


Figure: Example of model of a system

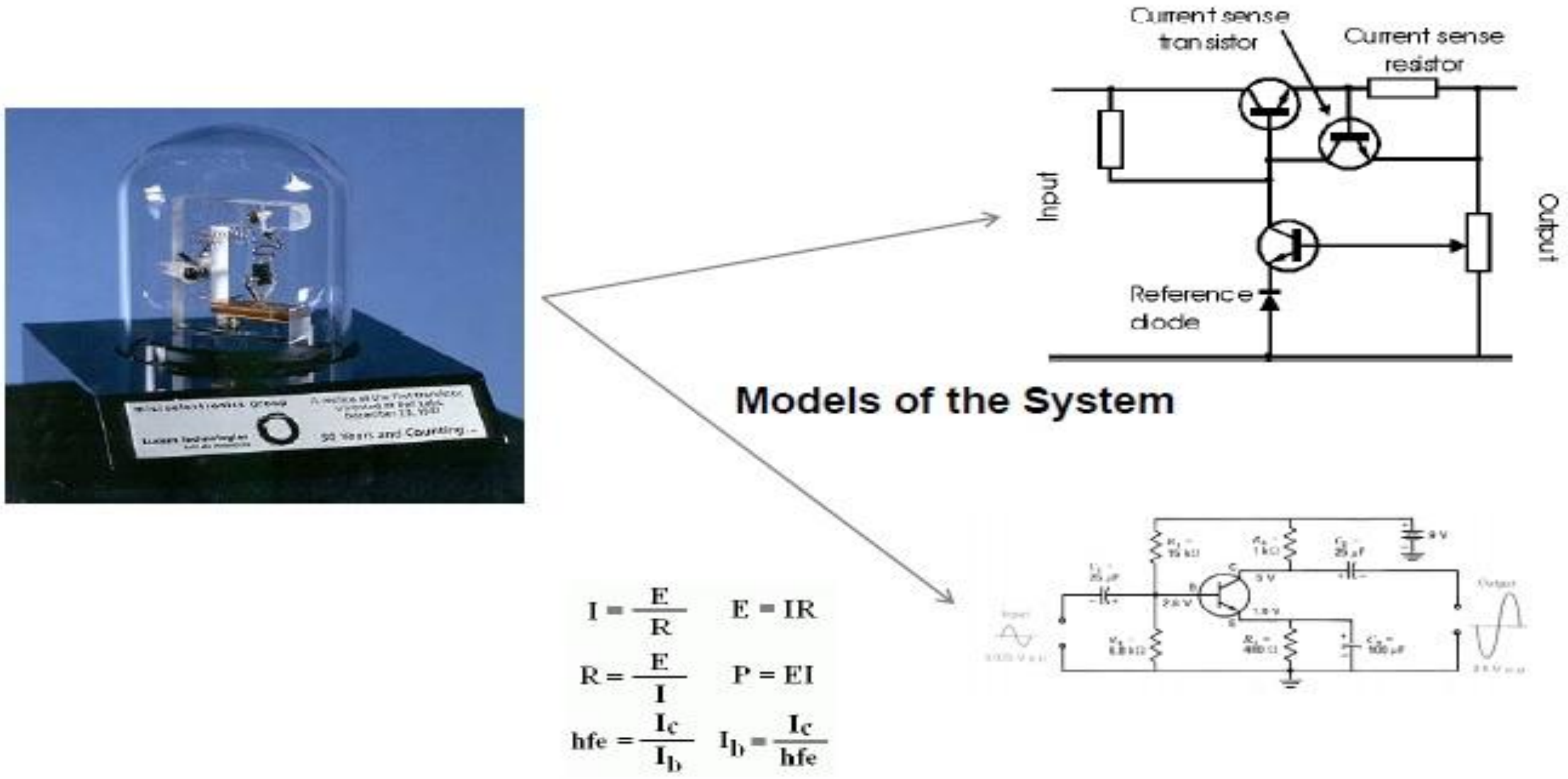


Figure: Example of model of a system

Why Simulation?

- It may be too difficult, hazardous, or expensive to observe a real, operational system
- A model can be used to investigate a variety of ‘what if’ questions about real-world system. Using simulation we can discover the change in system, output as the input parameter changes.
- Parts of the system may not be observable (e.g. internals of a silicon chip or biological system).
- Simulation can be used as an analysis tool for predicating the effect of changes.
- Simulation can be used as a design tool to predicate the performance of new system.

So it is better to do simulation before implementation.

When Simulation is Appropriate

- Simulation enable the study of internal interaction of a subsystem with complex system.
- Informational, organizational and environmental changes can be simulated and find their effects.
- A simulation model help us to gain knowledge about improvement of system.
- Finding important input parameters with changing simulation inputs.
- Simulation can be used with new design and policies before implementation.
- Simulating different capabilities for a machine can help determine the requirement.
- Simulation models designed for training make learning possible without the cost disruption
- The modern system (factory, wafer fabrication plant, service organization) is too complex that its internal interaction can be treated only by simulation

When Simulation is not Appropriate

- When problem can be solved analytically and easily.
- If it is easier to perform direct experiments.
- If the cost becomes too high such that cost exceeds saving.
- If resource and time are not available.
- If system behavior is too complex.

Discrete and Continuous System

Discrete System

- A discrete system is one in which the state variable(s) change only at a discrete set of points in time.
- Changes in the state variable(s) are predominantly discontinuous.
- Example: Number of customers waiting in line, Number of jobs in a queue, etc.

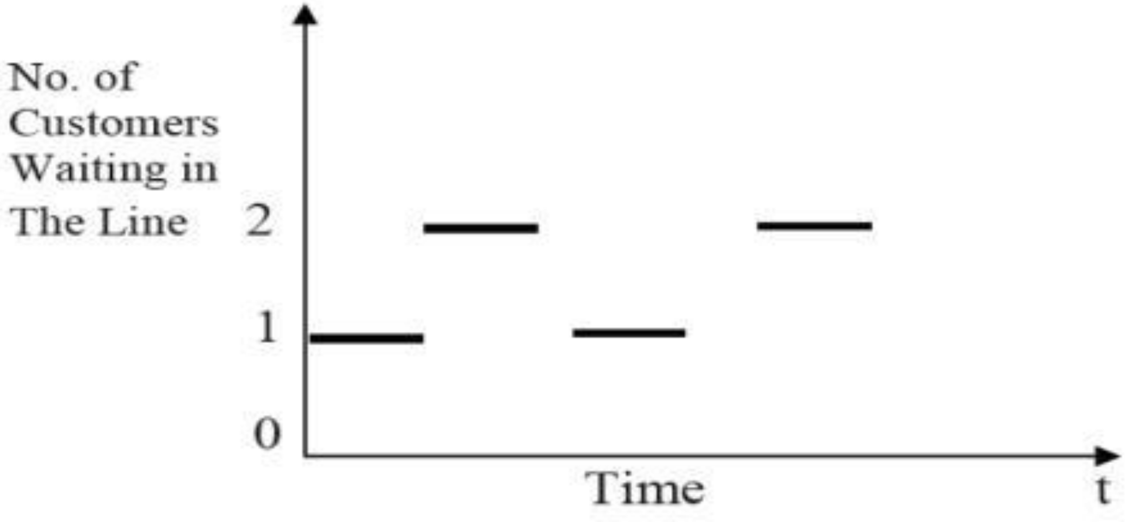


Figure: Discrete System Example

Continuous System

- A continuous system is one in which the state variable(s) change continuously over time.
- Changes in the state variable(s) are predominantly continuous and smooth without any delay.
- Example: Head of water behind the dam, etc.

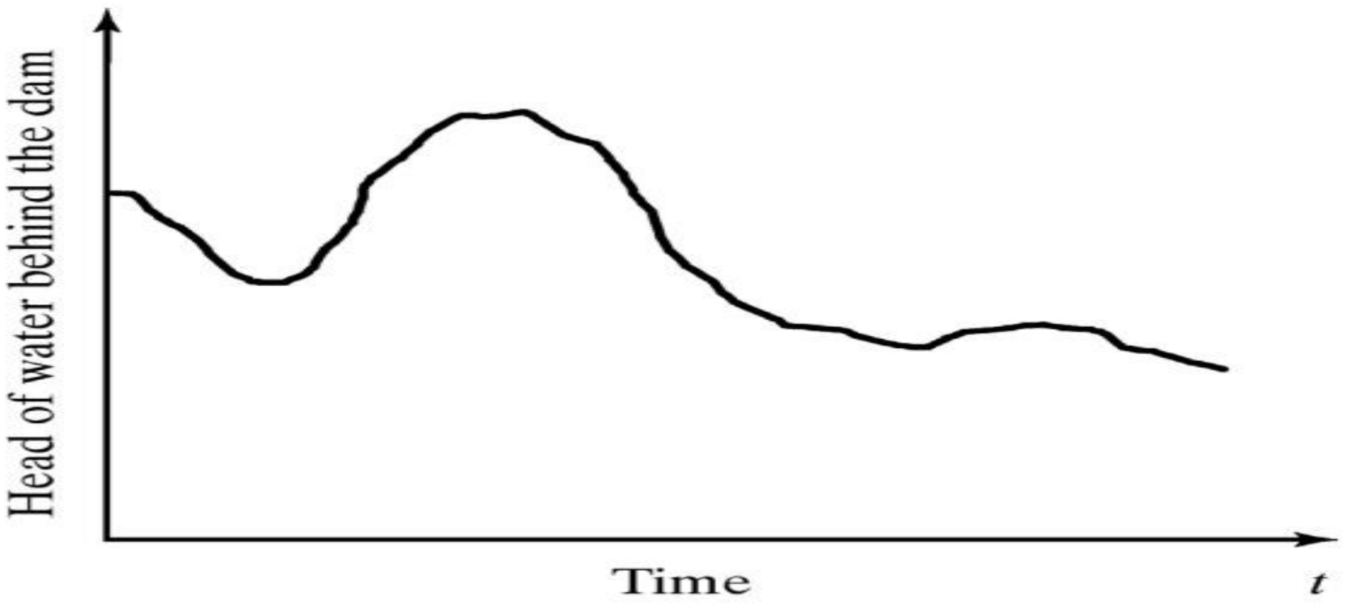
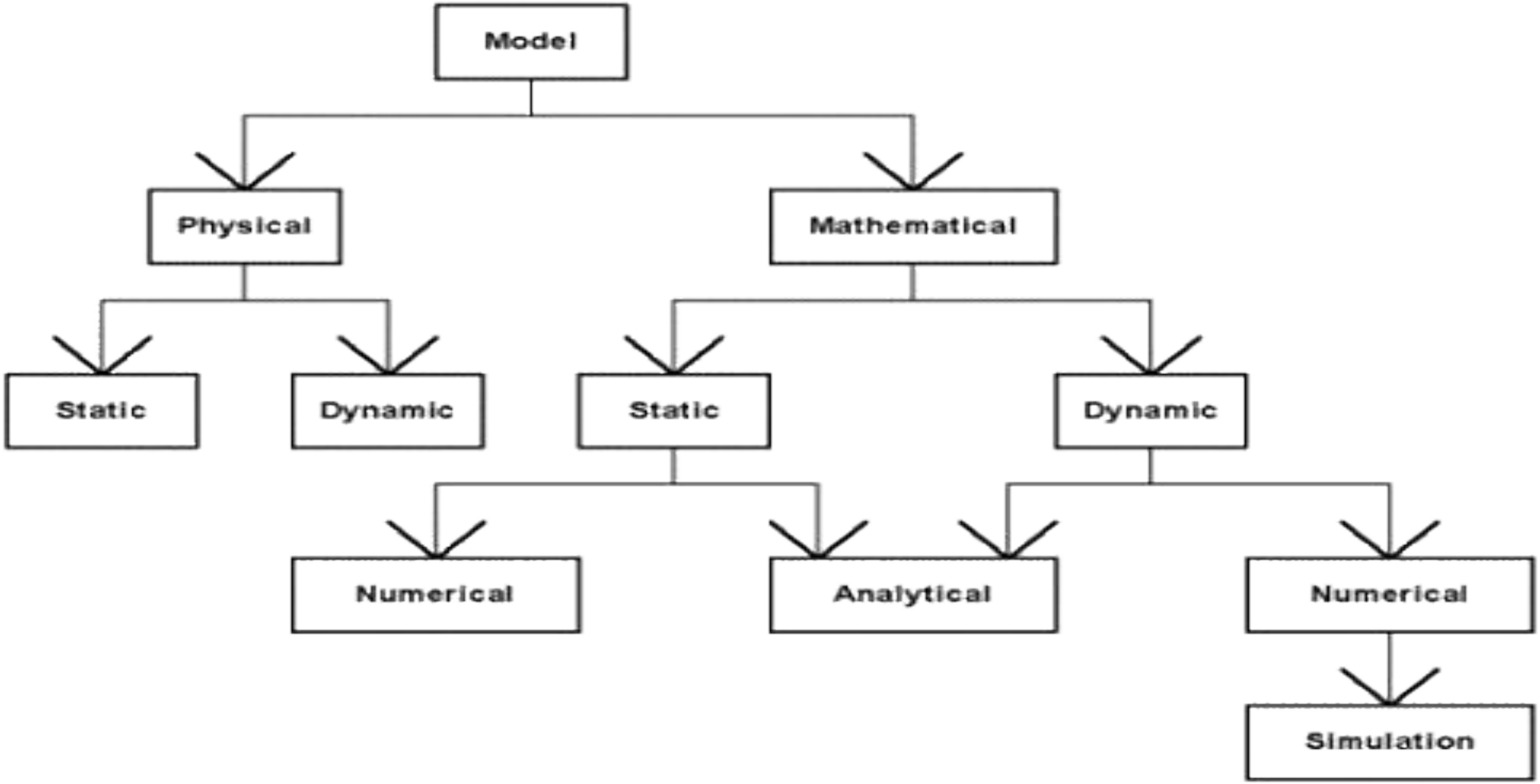


Figure: Continuous System Example

Types of Model



Physical Model

- Physical models are based on some analogy between such systems as mechanical and electrical or electrical and hydraulic.
- In a physical model of a system, the system attributes are represented by measurements such as voltage or the position of a shaft.
- The system activities are reflected in the physical laws that drive the model.
- For example the rate at which the shaft of a DC motor turns depends on the voltage applied to the motor.

Mathematical Model

- Mathematical models use symbolic notation and mathematical equation to represent a system.
- The system attributes are represented by variables, and the activities are represented by mathematical functions that interrelate the variables.

Static Model

- It is a type of model where time is not a significant variable.
- It is a representation of system at a particular point in time i.e. time plays no role.

Dynamic Model

- It is a type of model where time plays significant role and is a significant variable.
- It is the representation of a system that evolves over time.
- It describes the time-varying relationships.

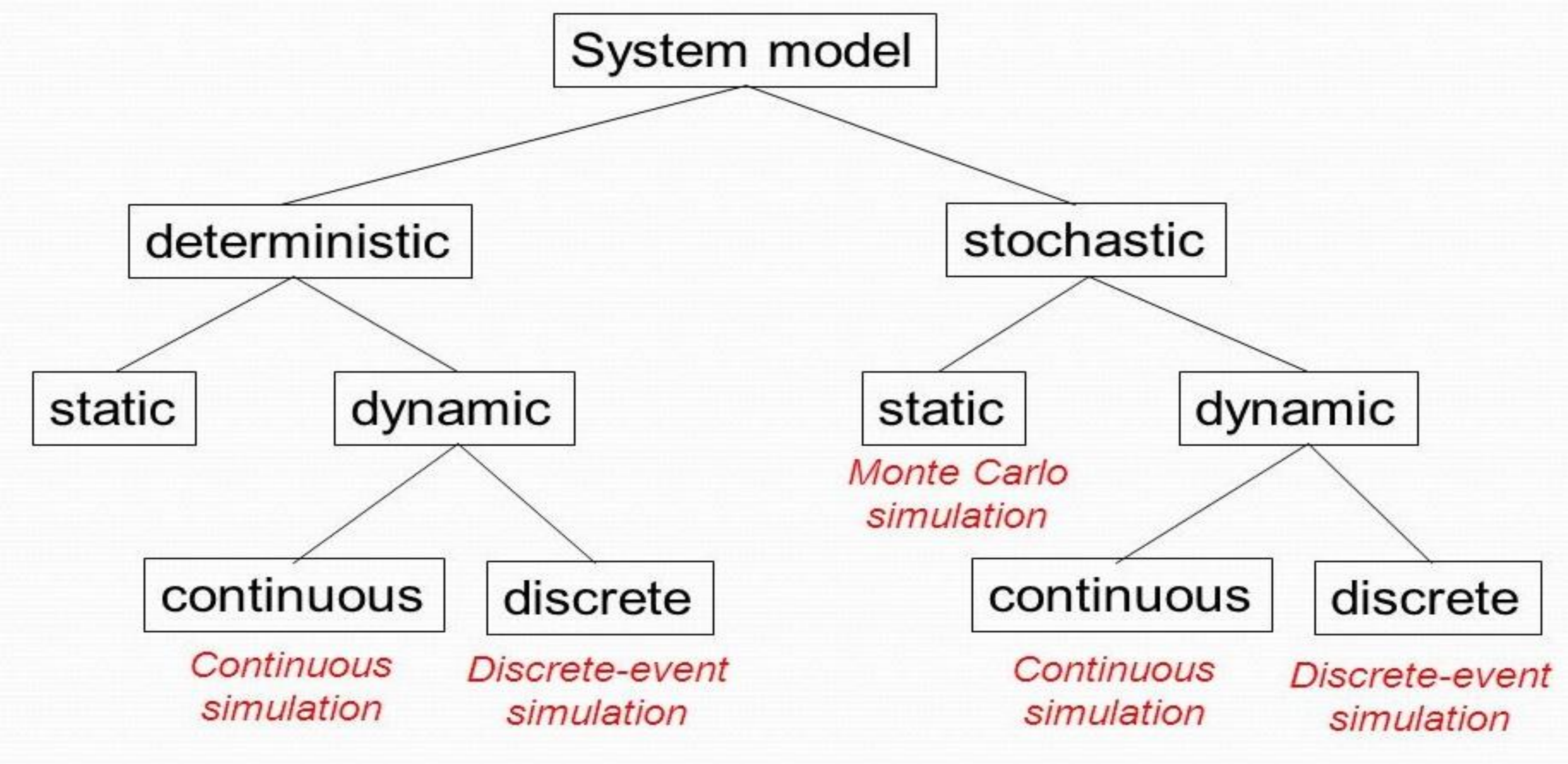
Analytical Model

- It is the one which is solved by using the deductive reasoning of mathematical theory.

Mathematical Model

- It is the one which is solved by using computational procedures.

Types of Simulation Model



Deterministic Simulation Model

- Deterministic models have a known set of inputs, which result into unique set of outputs.
- None of the system property is random.

Stochastic Simulation Model

- In stochastic model, there are one or more random input variables, which lead to random outputs.

Continuous Simulation Model

- Continuous simulation model represents system in which the state of the system changes continuously with time.

Discrete Simulation Model

- Discrete simulation model represents system in which the state of the system changes at discrete points.

Deterministic vs Stochastic Simulation Model

Deterministic Model	Stochastic Model
Deterministic models have known set of inputs which result in unique set of outputs.	Stochastic models have one or more random inputs which lead to random outputs.
Doesn’t contain random elements. Output is deterministic quantity.	Contains random(probabilistic) elements. Output is random quantity.
The functional relationships that exists are known with certainty.	There are some uncertain functional relationships.
Examples: Simulation of chemical reaction based on differential equations, simulation of digital circuits, etc.	Examples: Queuing Models like arrival time of customers at a restaurant, amount of time required to service a customer, etc.

Static vs Dynamic Simulation Model

Static Model	Dynamic Model
Model represents a system that doesn’t evolve over time.	Model represents a system that evolves over time.
Time doesn’t play important role. Model represents system at a particular point of time.	Time plays a vital role.
Static model is more structural than behavioral.	Dynamic model is more behavioral than structural.
Static model is more rigid than dynamic modeling as it is a time independent view of a system.	Dynamic modeling is flexible as it can change with time.
Example: Monte Carlo Simulation, Model that calculates mechanical stress in a bridge, etc.	Example: Model of a processor, etc.

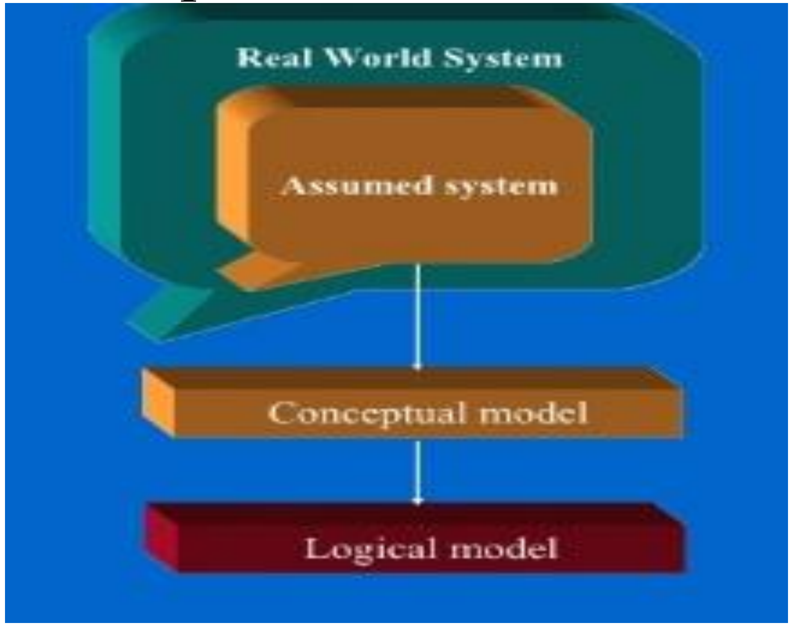
Continuous vs Discrete Simulation Model

Continuous Model	Discrete Model
Model represents system in which the state of the system changes continuously with time.	Model represents system in which the state of the system changes at discrete points.
The state variables change in a continuous way.	The state variables change only at a countable number of points in time.
Example: Model representing velocity of fluid in a pipe or channels, etc.	Example: Model of a system representing number of jobs in a queue, etc.

Steps in Simulation Study

1. **Problem formation**: The initial step involves defining the goals of the study and determing what needs to be solved. The problem is further defined through objective observations of the process to be studied

2. **Model Conceptualization:** This phase involves conceptualization of model which involves establishing a reasonable model. Essential features of the real world system are abstracted according to which an Assumed system is developed. From the Assumed system a conceptual model is developed which includes a more detailed specification of the system, important entities, relationships which is further developed into a logical model..



3. Data Collection: In this phase first the type of data to collect is determined and collection of data for input analysis and validation is done.

4. Model Translation: The model is translated into programming language. Choices range from general purpose languages such as C, C++, Fortran or simulation programs such as Arena.

5. Verification and Validation: Verification is the process of ensuring that the model behaves as intended. Validation is the process of determining whether the model accurately represents the system or not. Verification is performed before validation. Model verification answers for Did we build the model right? where as validation answers for Did we build the right model?

6. Experimental Design: The alternatives that are to be simulated must be determined. Factors such as number of simulations to run, length of each run, type of output data are determined.

7. Simulation Run and Analysis: The simulation is now run and the output of the simulation is collected and hence analyzed. The result is interpreted.

8. Documentation and Report: Documentation of the final model is prepared and the result of the simulation is reported. There are two types of documentation.

9. Implementation: The output of the simulation is analyzed and if expected output is achieved then finally the assumed system is implemented.

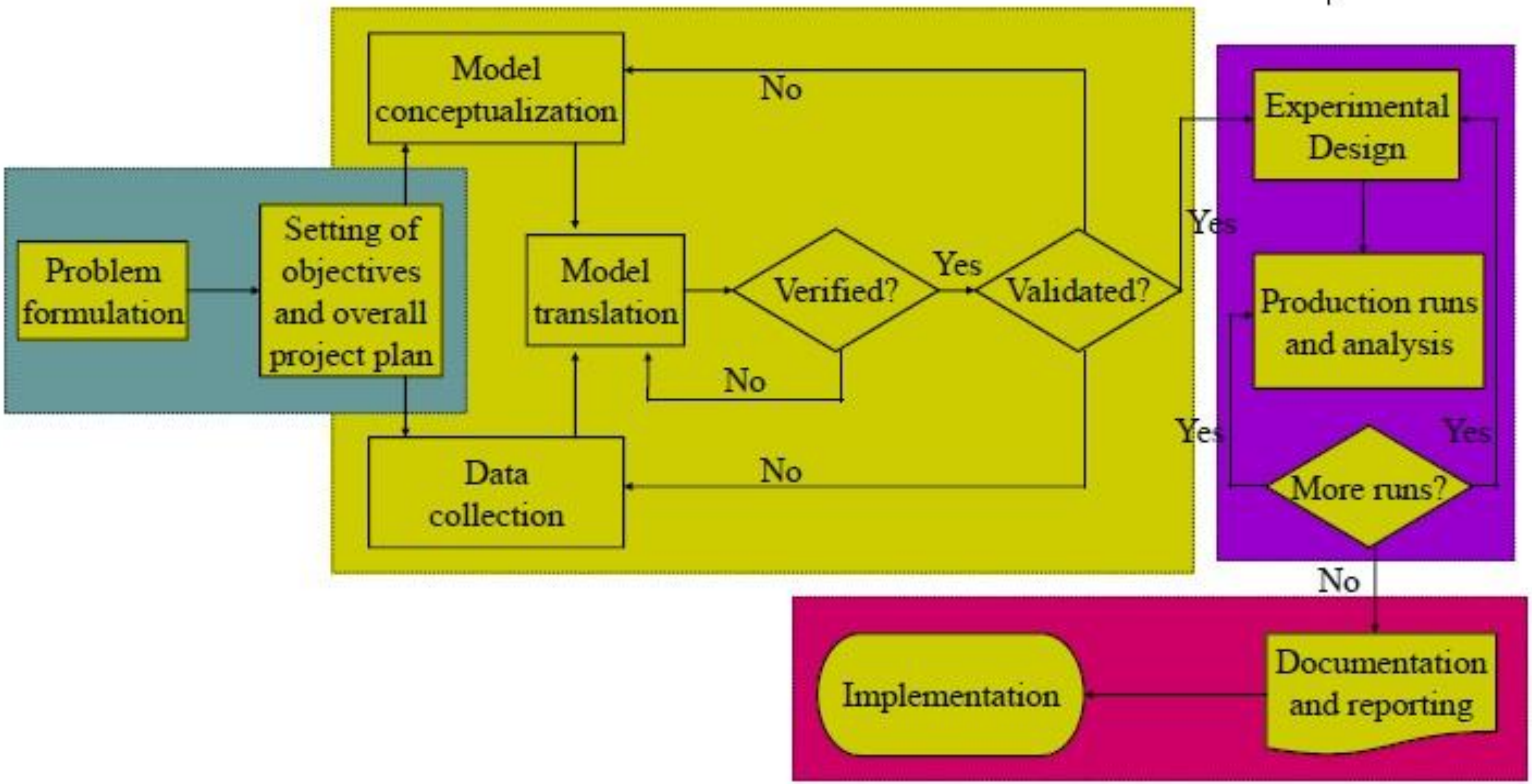
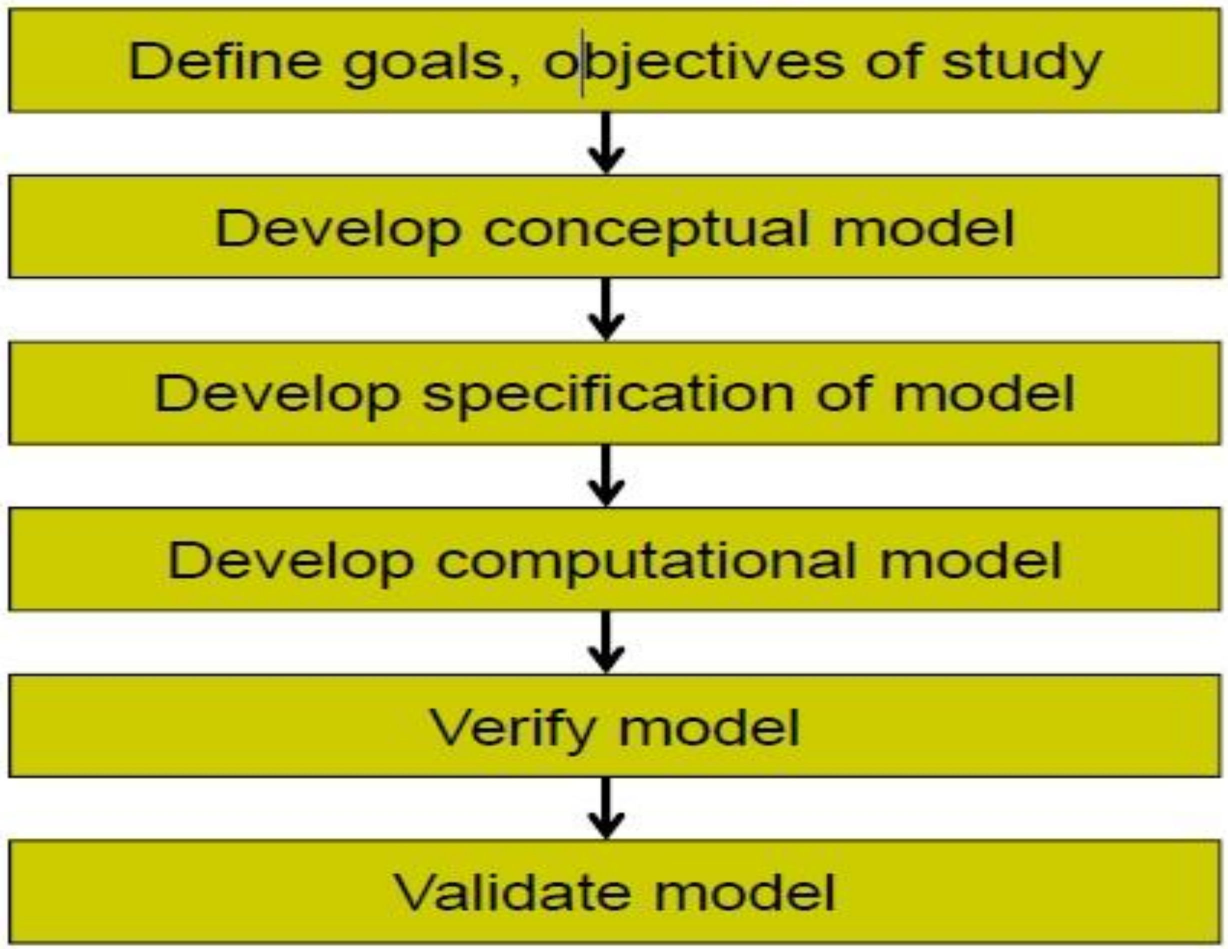


Figure: Flowchart For Steps In Simulation Study

Model Development Lifecycle



Steps in Model Development Life Cycle

1. **Define goals, objectives of study:** The goals and objectives for which the model is being developed should be identified and defined clearly.
2. **Develop Conceptual Model:** Once the goals and objectives are defined, the conceptual model should be developed now. A conceptual model is a representation of a system, made of the composition of concepts which are used to help people know, understand or simulate a subject the model represents. During the development of conceptual model, the main idea and concepts about the system for which the model is being developed must be found.
3. **Develop Specification of Model:** This phase involves a more detailed specification of the model. Collection of data, development of necessary algorithms are done in this phase. Empirical data or probability distributions often used in this phase.
4. **Develop Computational Model:** A computational model is a mathematical model in computational science that requires extensive computational resources to study the behavior of complex system. It is the executable simulation model. The specification model is developed into computational model in this phase.

5. Verify Model: This phase involves the verification of model. Verification is the process of ensuring that the model behaves as intended. Model verification answers for Did we build the model right?, Does the computational model match the specification model?, etc.

6. Validate Model: This phase involves the validation of model. Validation is the process of determining whether the model accurately represents the system or not. Model validation answers for Did we build the right model?, Does the computational model match the actual system?, etc.

Advantages and Disadvantages of Simulation

Main Advantages

- Simulation helps to learn about real system, without having the system at all. It helps to study the behavior of a system without building it.
- New hardware designs, physical layouts, transportation systems and various systems can be tested without committing resources for their acquisition.
- Simulation Models are comparatively flexible and can be modified to accommodate the changing environment to the real situation.
- Simulation technique is easier to use and can be used for wide range of situations.
- In systems like nuclear reactors where millions of events take place per second, simulation can expand the time to required level.
- Results are accurate in general, compared to analytical model.
- Help to find un-expected phenomenon, behavior of the system.
- Easy to perform ``What-If'' analysis.

Main Disadvantages

- Expensive and difficult to build a simulation model. Model building requires special training.
- Expensive to conduct simulation.
- Sometimes it is difficult to interpret the simulation results. Since most simulation outputs are essentially random variables, it may be hard to determine whether an observation is a result of system interrelations or randomness.
- Simulation results may be time consuming.

Applications of Simulation

- **Manufacturing**: Design analysis and optimization of production system, materials management, capacity planning, layout planning, and performance evaluation, evaluation of process quality.
- **Business**: Market analysis, prediction of consumer behavior, and optimization of marketing strategy and logistics, comparative evaluation of marketing campaigns.
- **Military**: Testing of alternative combat strategies, air operations, sea operations, simulated war exercises, practicing ordinance effectiveness, inventory management.
- **Healthcare applications**: Applications such as planning of health services, expected patient density, facilities requirement, hospital staffing , estimating the effectiveness of a health care program.
- **Communication Applications**: Applications such as network design, and optimization, evaluating network reliability, manpower planning, sizing of message buffers.

- **Computer Applications**: Can be applicable in fields such as designing hardware configurations and operating system protocols, sharing networking, gaming.
- **Economic applications**: Can be used in portfolio management, forecasting impact of Govt. Policies and international market fluctuations on the economy. Budgeting and forecasting market fluctuations.
- **Transportation applications**: Design and testing of alternative transportation policies, transportation networks-roads, railways, airways etc. Evaluation of timetables, traffic planning.
- **Environment application**: Solid waste management, performance evaluation of environmental programs, evaluation of pollution control systems.
- **Biological applications**: Such as population genetics and spread of epidemics.