Engineering Analysis and Design

(Modelling and Simulation)

Course Code: CO-207

Unit 1

Contents of Unit-1

- Definition of System
- Types of system: continuous and discrete
- Modelling process and definition of a model
- The nature of simulation
- Simulation model - static, dynamic, deterministic stochastic continuous, discrete models.

Introduction to System

- **System is defined as a set of ideas or rules for organizing something; a particular way of doing something**
- **A system is a collection of elements or components that are organized for a common purpose. For Example :**
  - A computer system consists of hardware components that have been carefully chosen so that they work well together and software components or programs that run in the computer.
  - All of nature and the universe can be said to be a system. We've coined a word, ecosystem, for the systems on Earth that affect life systems.
- **In Terms of Simulation and Modelling :**
  - A systems is defined as **a group of objects that are joined together** in some **regular interaction** towards the **accomplishment of some purpose**. For Example:

    An Automobile Factory : **Machine**, **component parts** and **workers** operate jointly along **Assembly line**.

Introduction to System (cont.)

- 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. [Schimidt and Taylor(1970)].
- In practice, what is meant by “the system” depends on the objectives of a particular study.
- The collection of entities that comprise a system for one study might be only a subset of the overall system for another.

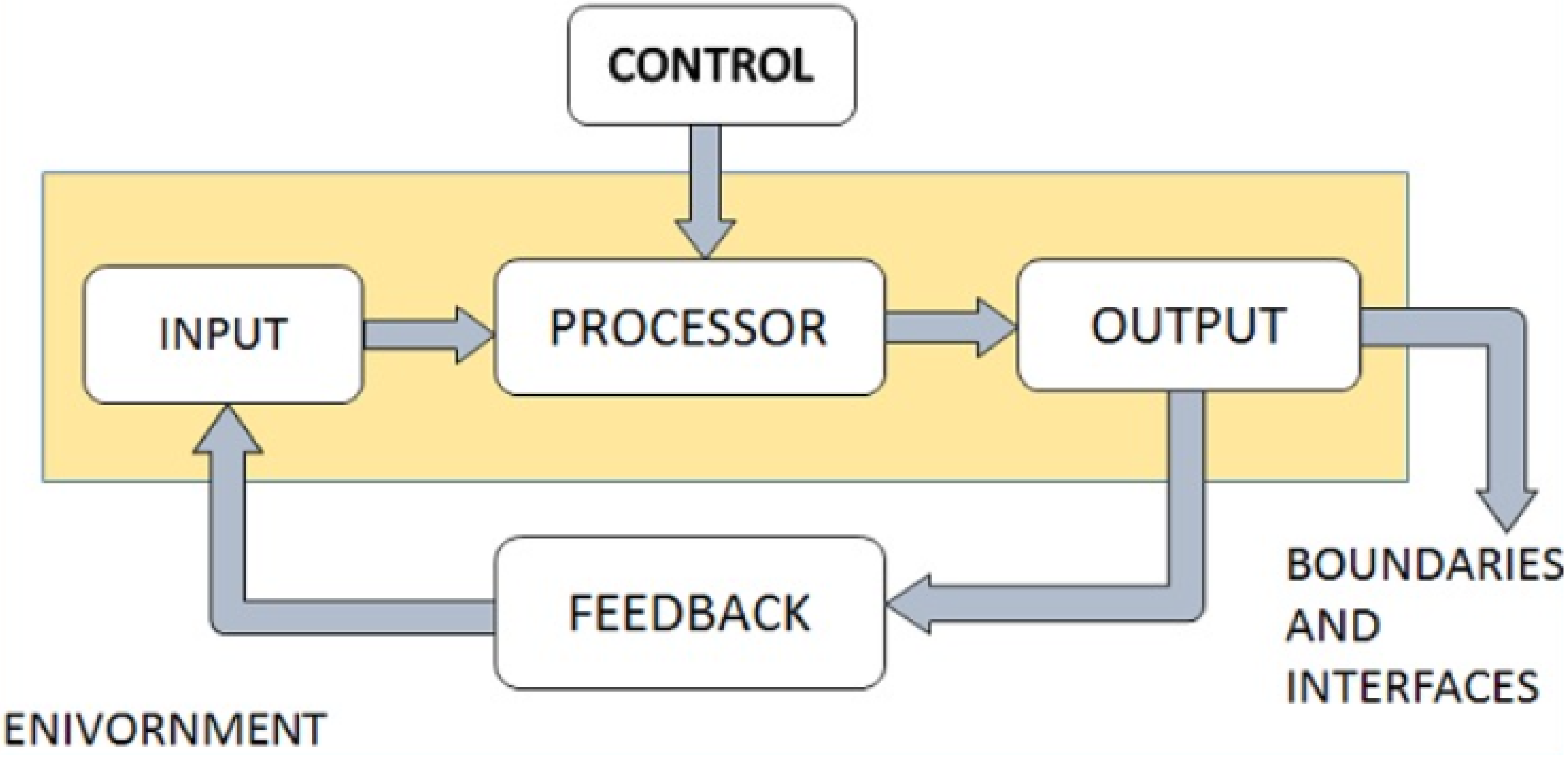
Introduction to System(cont.)

- If one wants to study a bank to determine the number of tellers needed to provide adequate service for customers who want just to cash a check or make a savings deposit, the system can be defined to be that portion of the bank consisting of the tellers and the customers waiting in line or being served.

- If, on the other hand, the loan officer and the safe-deposit boxes are to be included, the definition of the system must be expanded in an obvious way

Introduction to System (cont.)

❑ Understanding a System with Example



Component organized to form a Computer System

Components of System

- **Entity:** An entity is **an object of interest** in a system. Ex: In the factory system, departments, orders, parts and products are The entities.
- **Attribute:** An attribute denotes **the property of an entity**. Ex: Quantities for each order, type of part, or number of machines in a Department are attributes of factory system.
- **Activity:** Any **process causing changes** in a system is called as an activity. Ex: Manufacturing process of the department.
- **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, state of the system mean a **description** of all the **entities**, **attributes** and **activities** as they exist at one point in time.

Components of system (cont.)

- **Event :**An event is defined as an **instantaneous occurrence** that may **change** the **state of the system.**
- **Endogenous System:** The term endogenous is used to describe **activities and events occurring within a system**. Ex: Drawing cash in a bank.
- **Exogenous System:** The term exogenous is used to **describe activities and events** in the environment that **affect the system**. Ex: Arrival of customers.
- **Closed System:** A system for which there is **no exogenous activity and event** is said to be a closed. Ex: Water in an insulated flask.
- **Open system:** A system for which **there is exogenous activity** and event is said to be a open. Ex: Bank system.

Example of a System and its Component

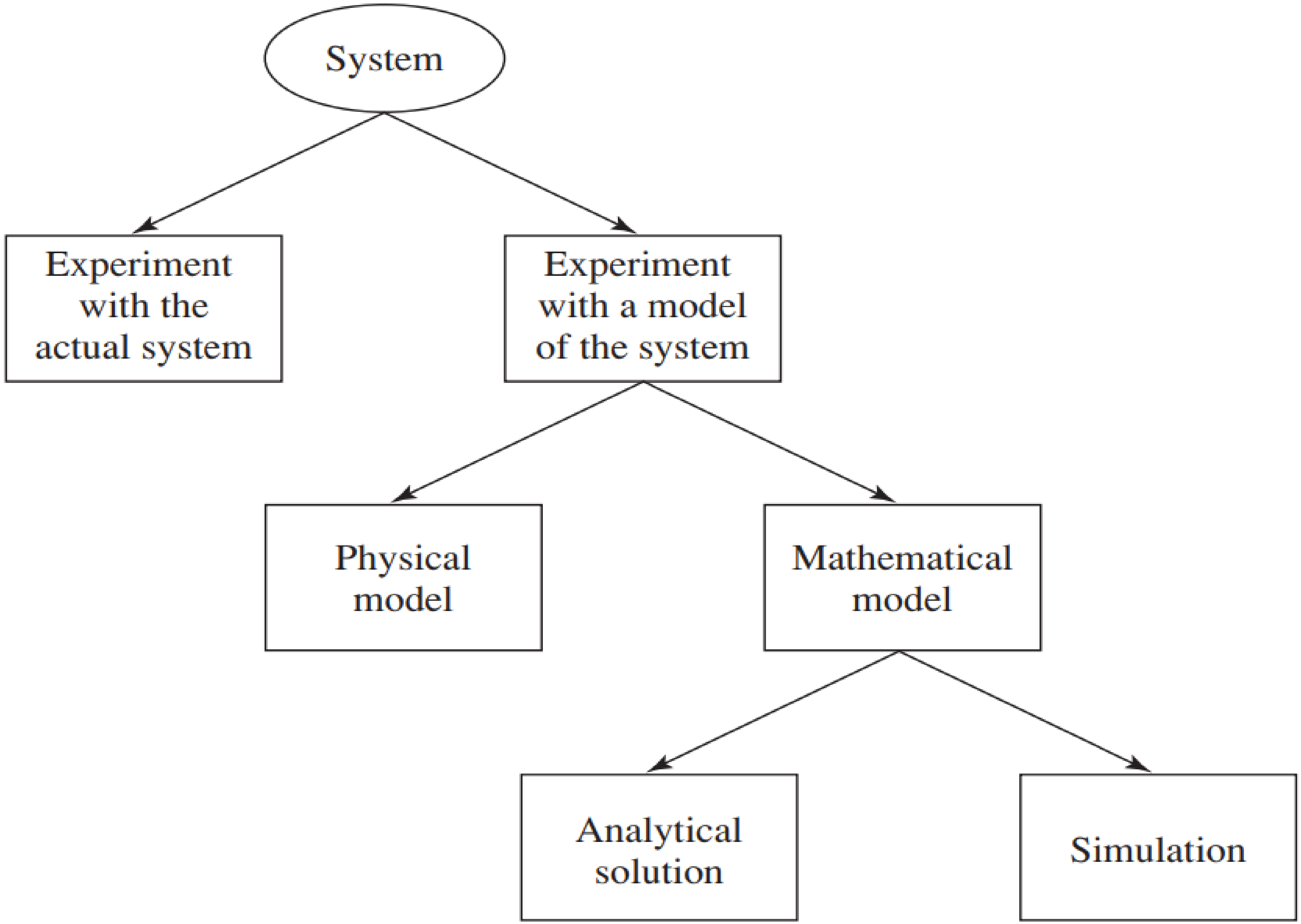
System	Entities	Attributes	Activities	Events	State Variables
Banking	Customers	Account Balance	Making Deposits	Arrival, Departure	Number of customer waiting

State of the System

- The state of a system 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.

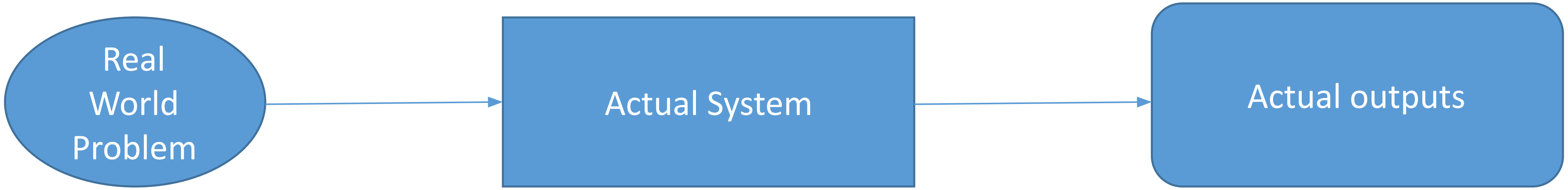
How to Study a System?



Experiment with the Actual System

- To Improve the understanding of how a system operates we need to experiment over the system.

- While analyzing or studying a system we must run the system over actual data.

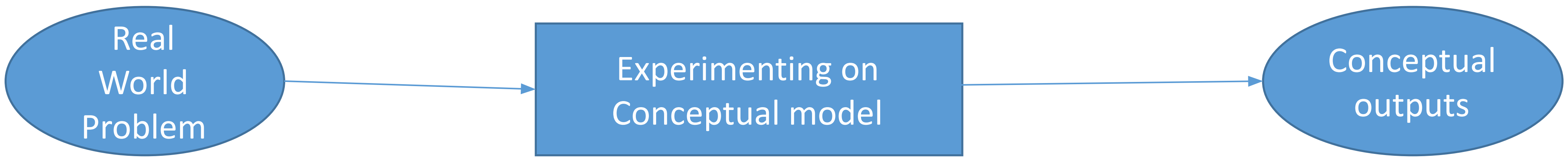


- When ever a real problem exist we can make a actual system and run the system to perform a set of task and see what are the results.

- But is it possible and feasible to make a actual system directly to solve a problem?

Experiment with a Model of the System

- Now we have a real problem and we need to find a solution, but as we know it is nearly impossible.
- Rather we can make a conceptual model first and then, do the experimentation over a model of a system.



- This may lead to many advantages that we will study in upcoming slides…

Physical Model

- A physical model is a smaller or larger physical copy of an object.

- A physical model is a simplified material representation, usually on a reduced scale, of an object or phenomenon that needs to investigated.

- The model can be used to simulate the physical conditions involved (temperature, waves, speed etc.) and to predict the particular constraints of the situation.

- These constraints can be taken into account and tested, and solutions implemented before undertaking the final steps of a project.

- Physical models are widely used in fields involving geometry, thermodynamics and fluid mechanics: urban development, naval construction, aeronautics etc.

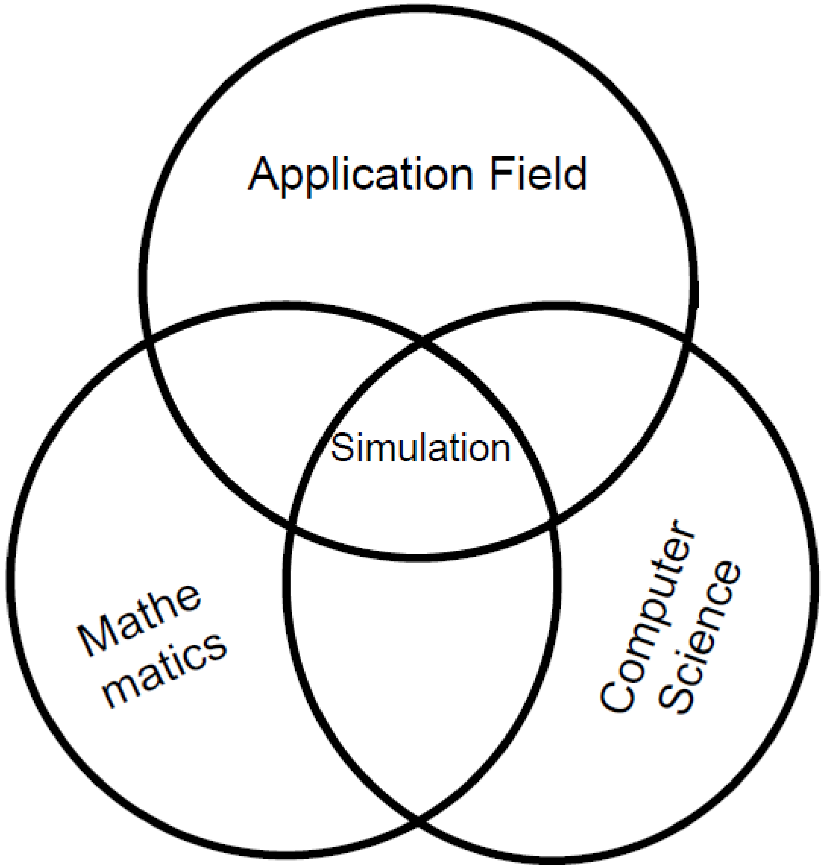
Mathematical Model

- A mathematical model is a description of a system using mathematical concepts and language.
- The process of developing a mathematical model is termed mathematical modeling.
- Mathematical modeling is the art of translating problems from an application area into tractable mathematical formulations whose theoretical and numerical analysis provides insight, answers, and guidance useful for the originating application. Mathematical modeling:
  - is indispensable in many applications
  - is successful in many further applications
  - gives precision and direction for problem solution
  - enables a thorough understanding of the system modeled
  - prepares the way for better design or control of a system

Analytical Solution

- An analytical solution involves framing the problem in a well-understood form and calculating the exact solution.
- Analytical solutions, also called closed-form solutions, are mathematical solutions in the form of math expressions.
  - **Transparency**: Because analytical solutions are presented as math expressions, they offer a clear view into how variables and interactions between variables affect the result.
  - **Efficiency**: Algorithms and models expressed with analytical solutions are often more efficient than equivalent numeric implementations. For example, to compute the solution of an ordinary differential equation for different values of its parametric inputs, it is often faster, more accurate, and more convenient to evaluate an analytical solution than to perform numerical integration.

Simulation



Application Field
Simulation
Mathe
matics
Computer
Science

Introduction to simulation

❑ Simulation Study

- ❑ Step 1: **Select** a real world system for study.
- ❑ Step 2: **Create** a Simulation Model for the selected real world system
- ❑ Step 3: **Perform** the experiment over the simulation model
- ❑ Step 4 : Simulation **analysis**
- ❑ Step 5: Reach to **conclusion**
- ❑ Step 6 : **Use these conclusion** to create the altered system
- ❑ Step 7: Goto **Step 1**

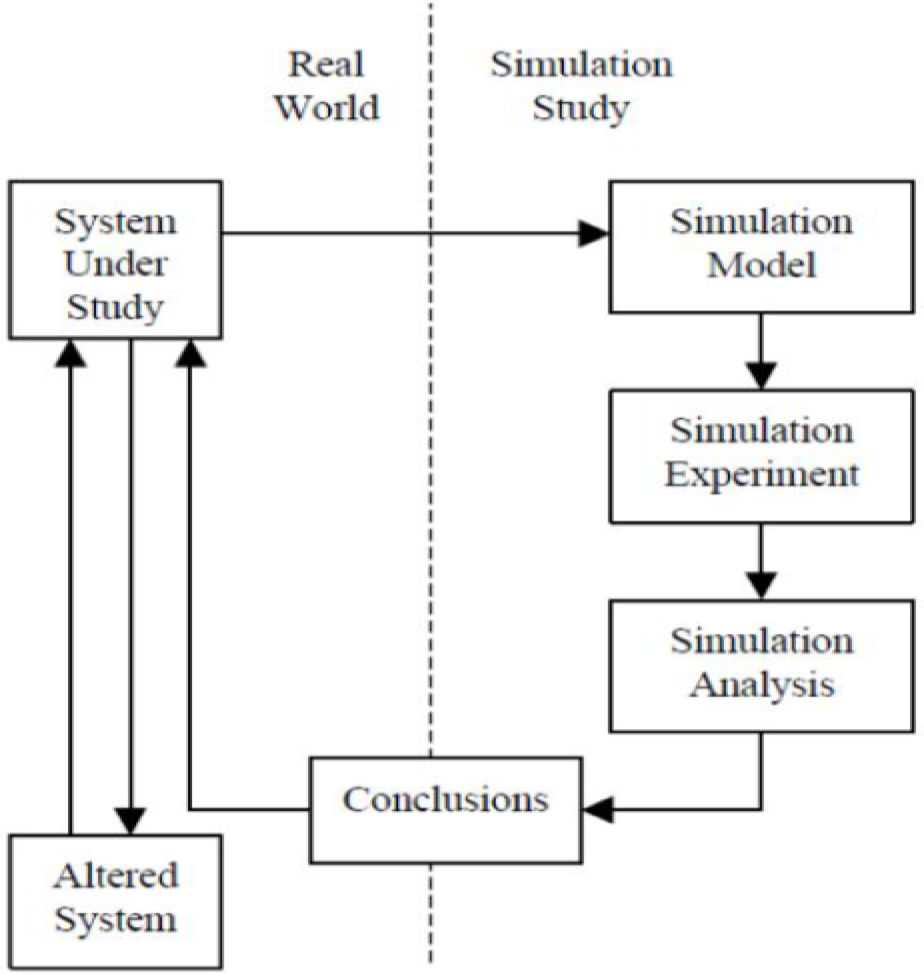


Figure 1: Simulation Study Schematic

Definition of Simulation

- A simulation is the **imitation** (Duplication) of the operation of real-world process or system over time.

- Generation of artificial history and observation of that observation history.

- A model construct a **conceptual framework** that describes a system.

- The **behaviour** of a system that **evolves over time** is studied by developing a simulation model

- The model takes a set of expressed assumptions:- Mathematical, logical-Symbolic relationship between the entities

History of Simulation

- **1940's: Monte Carlo method** is developed by physicists working on Manhattan project to study neutron scattering. Researchers include John von Neumann, Stanis law Ulan, Edward Teller, Herman Kahn
- **1950's:** First **special-purpose simulation languages** developed (e.g. IMSCRIPT by Harry Markowitz at RAND Institute)
- **1970's:** Research initiated on **mathematical foundations** of simulation
- **1980's: PC-based simulation** software developed, **graphical user interfaces**, object-oriented programming
- **1990's: Web-based simulation**, fancy animated graphics, simulation-based optimization, **Markov-chain Monte Carlo methods Simulation** has become ever **more prominent** as a method for studying complex systems in which uncertainty is present. In various surveys, simulation has been found to be the most frequently used tool of Operation Research practitioners. **Simulation is an interdisciplinary subject,** using ideas and techniques from Statistics, Probability, Number Theory, and Computer Science.

Goal of Modelling and Simulation

A model can be used to investigate a wide verity of "**what if**" questions about real-world system.

- Potential changes to the system can be simulated and predicate their impact on the system.
- Find adequate parameters before implementation.

- So simulation can be used as- Analysis tool for predicating the effect of changes- Design tool to predicate the performance of new system. It is better Implementation.

When Simulation is the Appropriate Tool

- 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**.
- A **plan simulation** can be **visualized** with animated simulation
- The modern system (factory, wafer fabrication plant, service organization) is **too complex** that its internal interaction can be treated only by simulation

Advantages of Simulation

- **New policies, operating procedures, information flows can be explored without disrupting ongoing operation of the real system**.

- **New hardware designs, physical layouts, transportation systems** and ... 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(clock is self-control).Insight can be obtained about interaction of variables and important variables to the performance.

- **Bottleneck analysis** can be performed to discover where work in process, the system is delayed.

- A simulation study can help in **understanding how the system operates.**

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).

- Simulation **results can be difficult to interpret**.

- Simulation **provides only estimates** of solution, only solves one parameter at a time, can take a large amount of development and/or computer time

Difficulties of Simulation

- Provides only individual, not general solutions
- Manpower and time-consuming
- Computing memory and time-intensive
- Difficult so experts are required
- Hard to interpret results
- Expensive

Areas of Application

- Manufacturing Applications
- Semiconductor Manufacturing
- Construction Engineering and project management
- Military application
- Logistics, Supply chain and distribution application
- Transportation modes and Traffic
- Business Process Simulation Health Care
- Automated Material Handling System (AMHS)(Test beds for functional testing of control-system software)
- Risk analysis (Insurance, portfolio,...)
- Computer Simulation(CPU, Memory,...)
- Network simulation (Internet backbone, LAN(Switch/Router), Wireless, PSTN (call center),...)

When to Use Simulation

- ❑ Study internals of a complex system e.g. biological system
- ❑ Optimize an existing design e.g. routing algorithms, assembly line
- ❑ Examine effect of environmental changes e.g. weather forecasting
- ❑ System is dangerous or destructive e.g. atom bomb, atomic reactor, missile launching
- ❑ Study importance of variables
- ❑ Verify analytic solutions (theories)
- ❑ Test new designs or policies
- ❑ Impossible to observe/influence/build the system

When to Use Simulation (cont.)

- When it allows inspection of system internals that might not otherwise be observable
- Observation of the simulation gives insights into system behavior
- System parameters can be adjusted in the simulation model allowing assessment of their sensitivity (scale of impact on overall system behavior)
- Simulation verifies analysis of a complex system, or can be used as a teaching tool to provide insight into analytical techniques
- A simulator can be used for instruction, avoiding tying up or damaging an expensive, actual system (e.g., a flight simulation vs. use of multimillion dollar aircraft)

Steps of Simulation

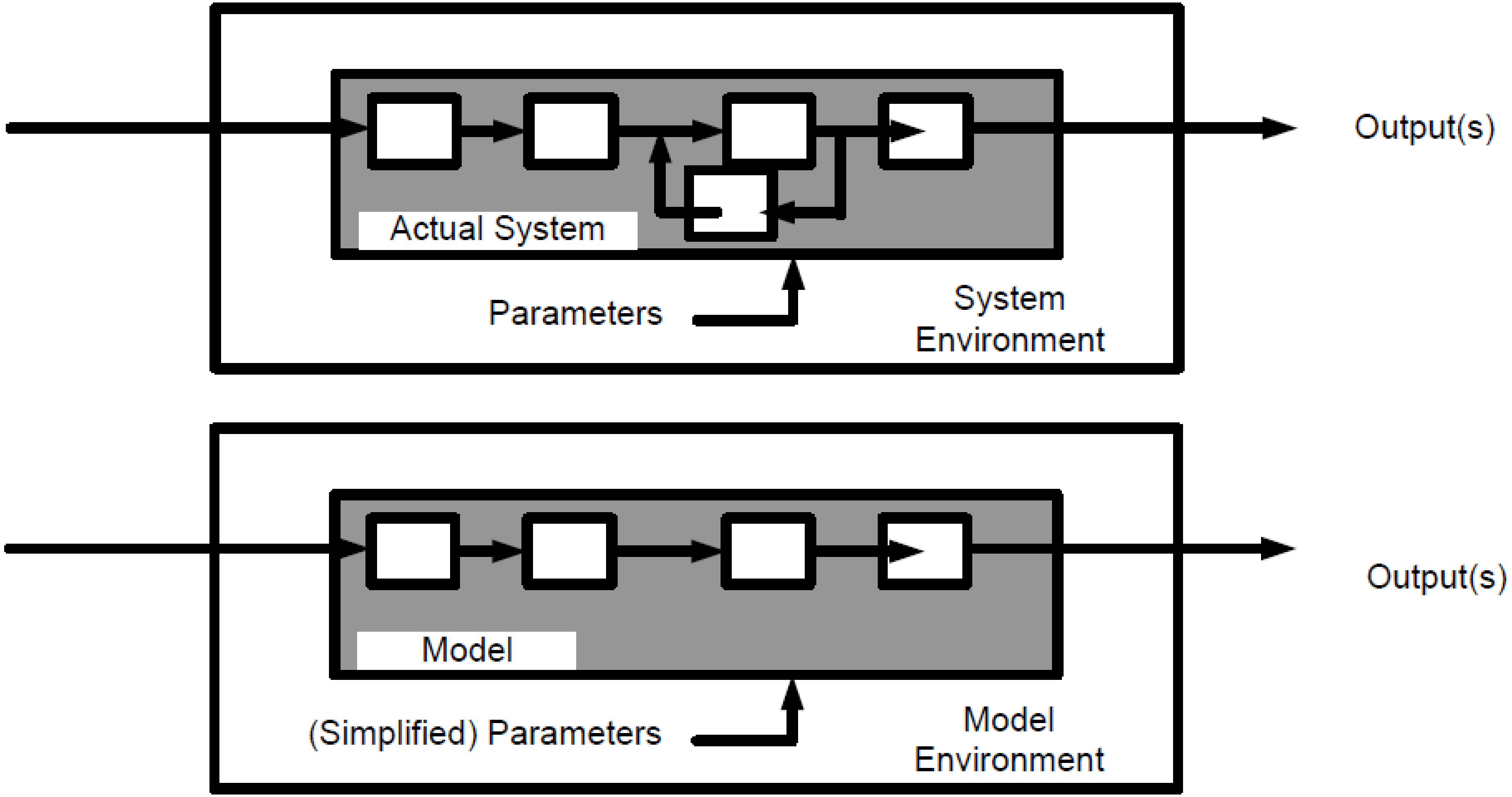
Study For developing a simulation model, designing a simulation experiment, and performing simulation analysis are:

- Step 1**. Identify** the problem.
- Step 2. **Formulate** the problem.
- Step 3. **Collect and process** real system **data**.
- Step 4. **Formulate and develop** a model.
- Step 5. **Validate** the model.
- Step 6. **Document model** for future use.
- Step 7. **Select** appropriate **experimental design**.
- Step 8. **Establish experimental conditions for runs**.
- Step 9. **Perform simulation** runs.
- Step 10. **Interpret and present results**.
- Step 11. **Recommend further course of action**.

Definition of a Model

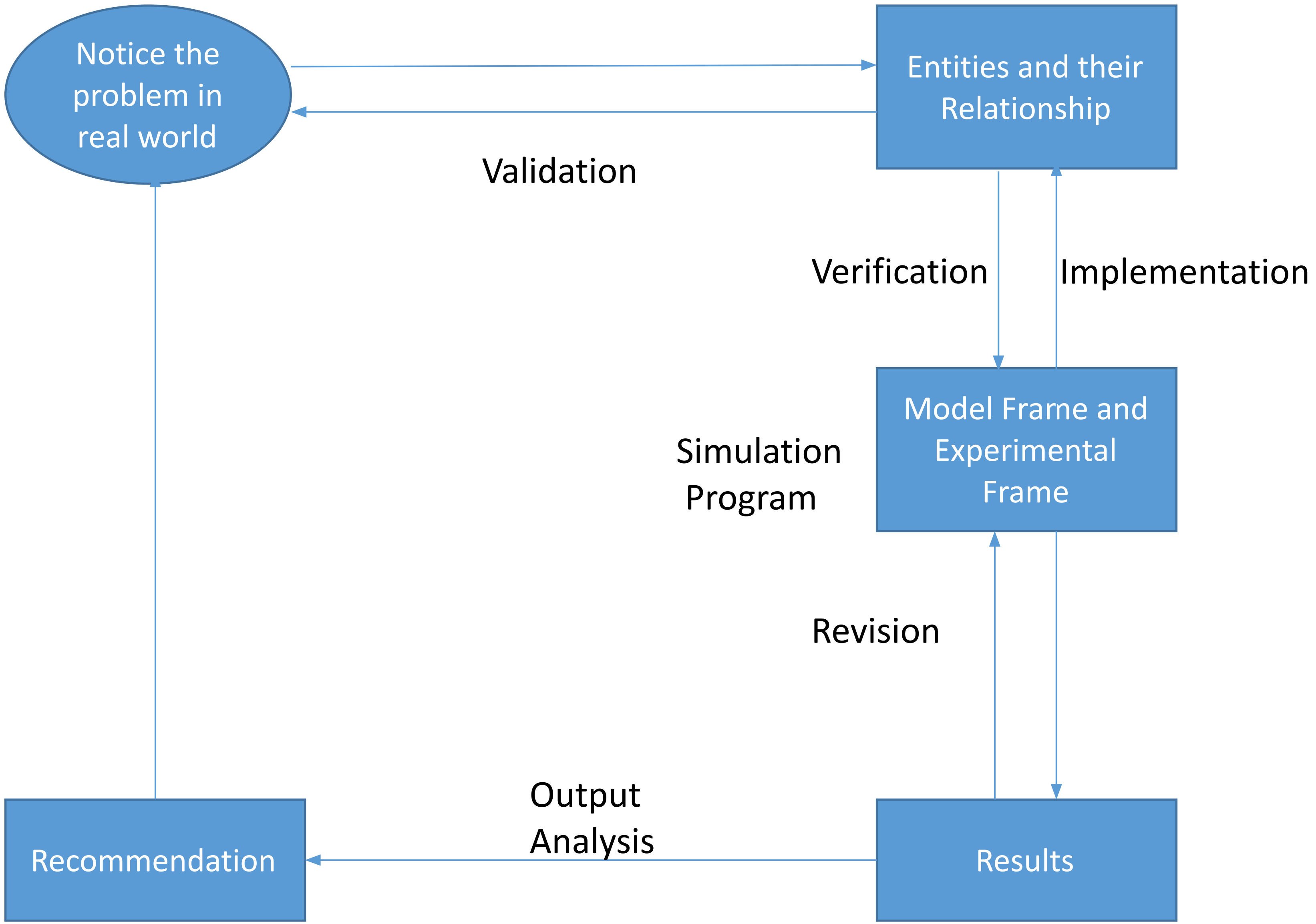
- **Model:** Simulation models consist of the **following components**: **system entities, input variables, performance measures, and functional relationships**.
- A model is a representation of an actual system
  - A model is an abstraction of the real system
  - Simplifying assumptions are used to capture (only) important behaviors
- **Modelling :** 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 to predict the effect of changes to the system. In other words, modelling is creating a model which represents a system including their properties. It is an act of building a model
- **Formally we can define, Modeling** is the **application of methods to analyze complex, real-world problems** in order **to make predictions** about what might happen with various actions.

Introduction to Model



Pictorial Representation of System Model

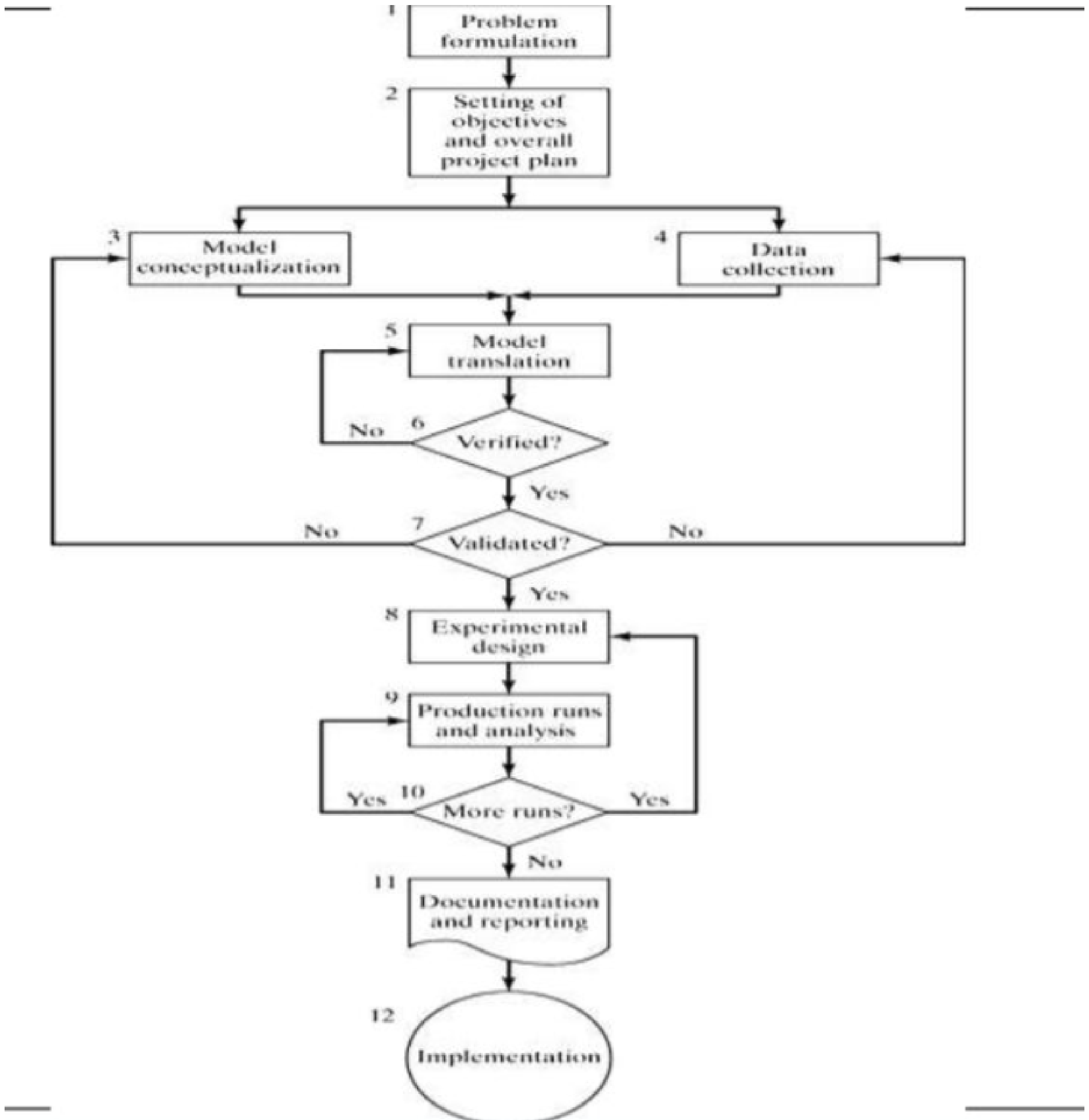
The Modelling Process



The Modelling Process

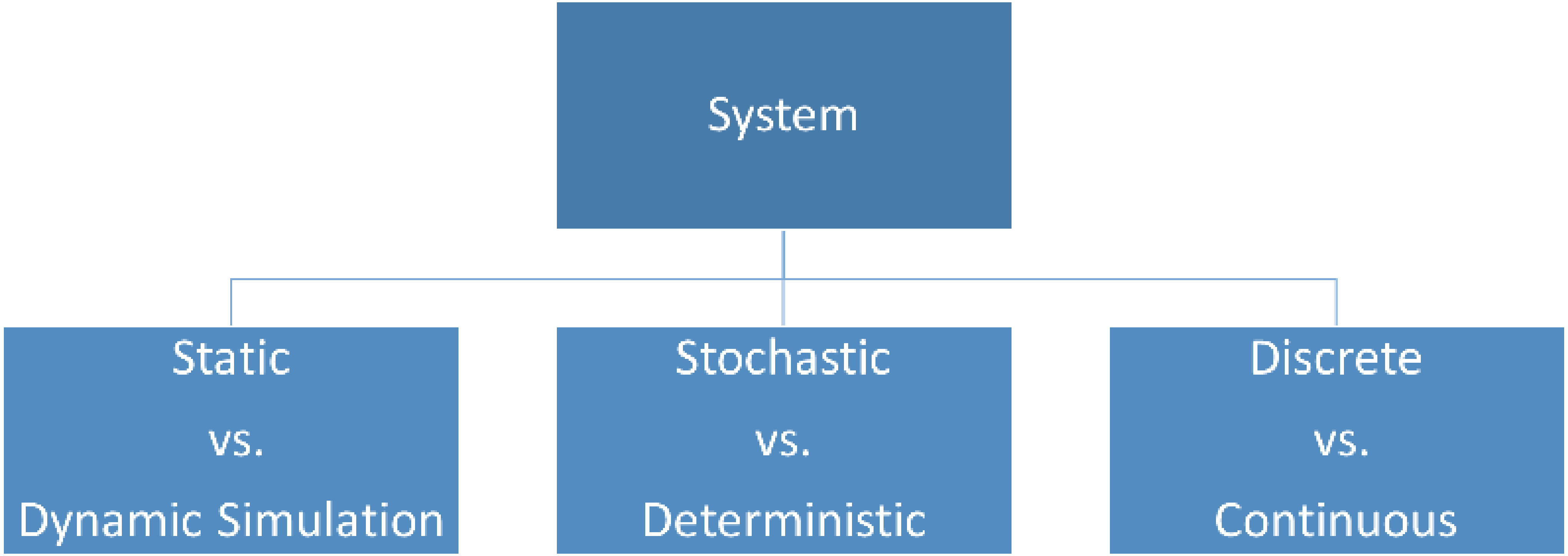
- Step 1- **Examine the problem:** In this stage,, we must understand the problem and choose its classification accordingly, such as deterministic or stochastic.
- Step 2- **Design a model:** In this stage, we have to perform the following simple tasks which help us design a model
  - **Collect data** asper the system behavior and future requirements.
  - **Analyze the system** features, its assumptions and necessary actions to be taken to make the model successful.
  - **Determine the variable names, functions, its relationships, and their applications** used in the model.
  - **Solve the model using a suitable technique** and verify the result. using verification methods. Next, validate the result.
  - **Prepare a report** which includes results, interpretations, conclusion, and suggestions..
- Step 3 **Provide recommendations** after completing the entire process related to the model. It includes investment, resources, algorithms, techniques, etc.

The Detailed Modelling Process



Classification of Models

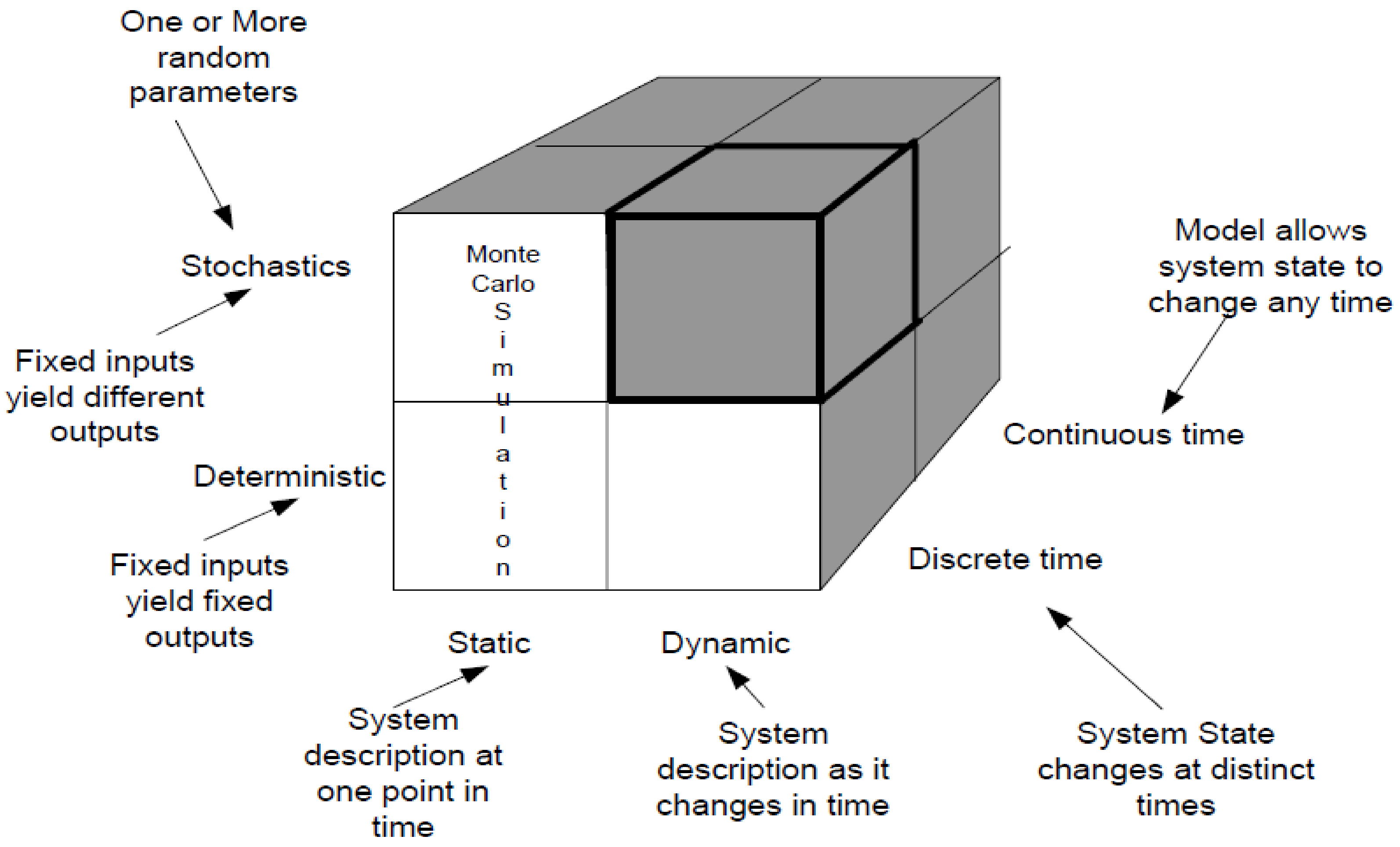
- A system can be classified into the following categories.



Classification of Models (cont.)

- Static vs. Dynamic Simulation - Static simulation include models which **are not affected with time**. For example: Monte Carlo Model. Dynamic Simulation include models which are affected with time.
- ~~Stochastic vs. Deterministic Systems - Stochastic systems **are not affected by randomness** and their output is not a random variable, whereas deterministic systems are affected by randomness and their output is a random variable.~~
- Discrete vs. Continuous Systems - Discrete **system is affected by the state variable changes at a discrete point of time**. Its behavior is depicted in the following graphical representation.

Classification of Models



Static vs. Dynamic-event simulation

- We can also classify models as static or dynamic.
- In a static model, we do not consider time, so that the model is comparable to a snapshot or a map.
- For example, a model of the weight of a salamander as being proportional to the cube of its length has variables for weight and length, but not for time.
- By contrast, in a dynamic model, time changes, so that such a model is comparable to an animated cartoon or a movie.
- For example, the number of salamanders in an area undergoing development changes with time; and, hence, a model of such a population is dynamic.
- Many of the models we consider in this text are dynamic and employ a static component as part of the dynamic model.
- Definitions A static model does not consider time, while a dynamic model changes with time.
- Static: A simulation of a system at one specific time, or a simulation in which time is not a relevant parameter for example, Monte Carlo & steady-state simulations.
- Dynamic: A simulation representing a system evolving over time for examples, the majority of simulation problems.

Deterministic Vs. Stochastic- Event Simulation Model

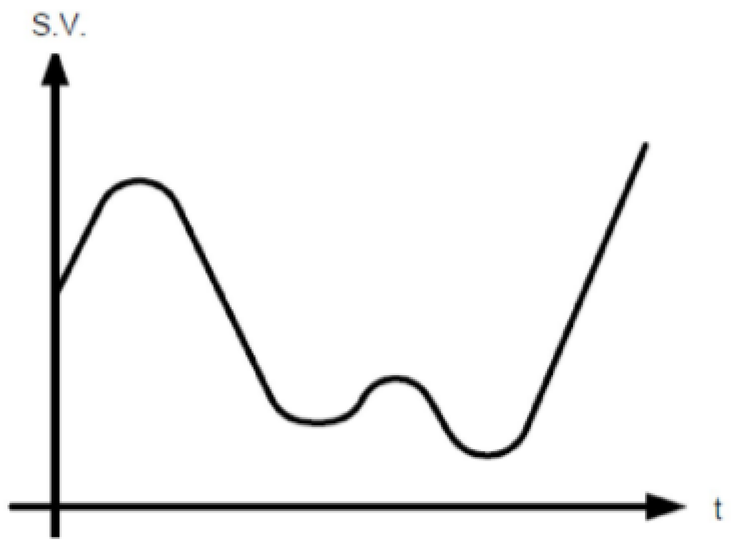
- A system exhibits probabilistic or stochastic behavior if an element of chance exists. Otherwise, it exhibits deterministic behavior.
- A probabilistic or stochastic model exhibits random effects, while a deterministic model does not.
- Deterministic: Randomness does not affect the behavior of the system.
- The output of the system is not a random variable.
- Stochastic: Randomness affects the behavior of the system. The output of the system is a random variable

Discrete vs. Continuous Event Simulation Model

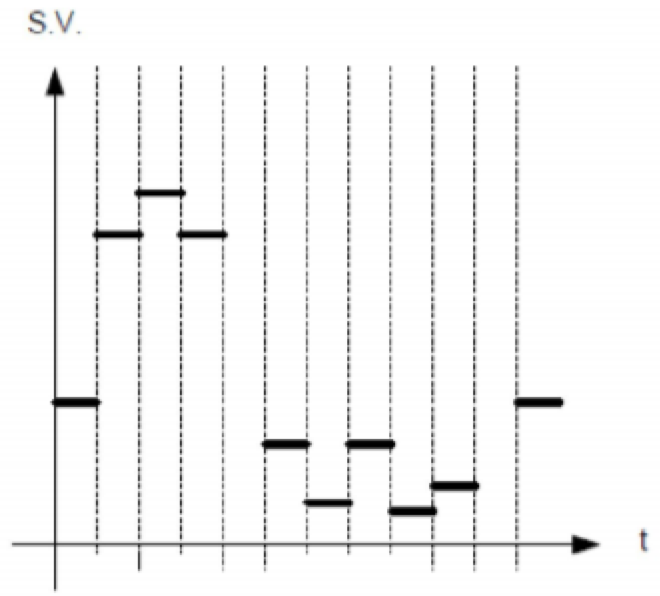
- When time changes continuously and smoothly, the model is continuous.
- If time changes in incremental steps, the model is discrete.
- A discrete model is analogous to a movie.
- A sequence of frames moves so quickly that the viewer perceives motion. However, in a live play, the action is continuous.
- Just as a discrete sequence of movie frames represents the continuous motion of actors, we often develop discrete computer models of continuous situations .
- Definitions In a continuous model, time changes continuously, while in a discrete model time changes in incremental steps.
- Continuous: State variables change continuously as a function of time (Fig 1) and generally analytical method like deductive mathematical reasoning is used to define and solve the system.
- State Variable (S.V.) = f (t)

Discrete vs. Continuous Event Simulation Model

- Discrete: State variables change at discrete points in time (Fig 2) and generally numerical method like computational procedures is used to solve mathematical models.
- State Variable(S.V.) = f(n t)



Continuous Model behavior is shown



Discrete Model behavior is shown

Examples of Different Systems

- Queue length at a cash machine: **Stochastic, Discrete Time, Discrete System**
- The motion of the planets: **Deterministic, Continuous Time, Discrete** System
- Logic circuit in a computer: **Deterministic, Discrete Time, Discrete** System
- Flow of air around a car: **Deterministic, Continuous Time, Continuous** System
- Closing prices of the 30 DAX shares: **Stochastic, Discrete Time, Discrete** System