Introduction to Modeling and Simulation

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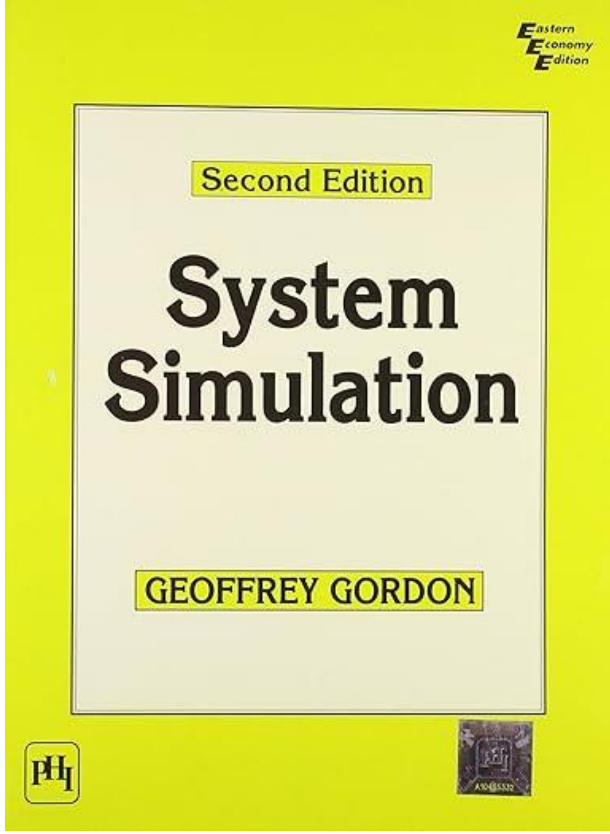
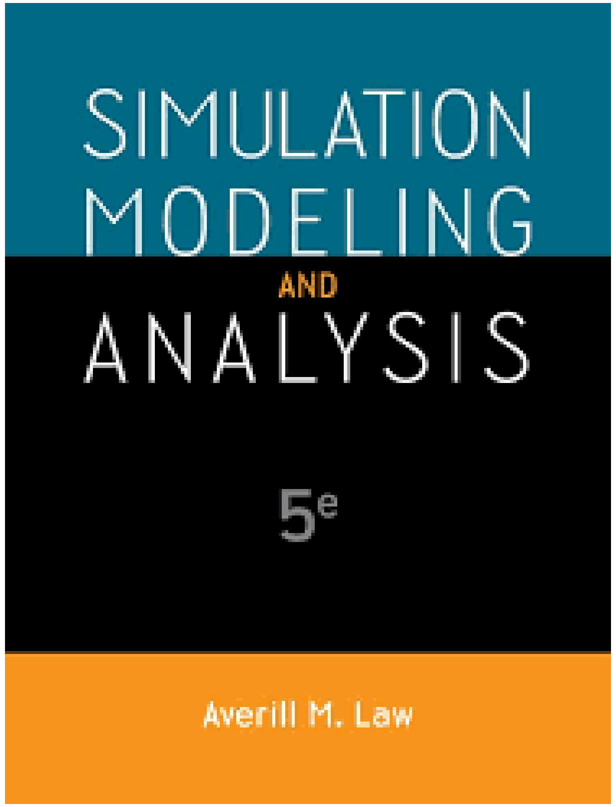
Course Objective

- To introduce the details of modeling and simulation technologies to the students.
- To provide the students with the knowledge of
  - discrete and continuous systems
  - generation of random variables
  - analysis of simulation output
  - simulation languages.

Text Books



G. Gorden, System Simulation, Prentice Hall of India
ISBN: 9788120301405



A.M. Law and W.D. Kelton, Simulation Modeling and Analysis, McGraw Hill, 1991

Syllabus

1. **Introduction to Modeling and Simulation**
   1.1 System concept
   1.2 System Environment
   1.3 Stochastic Activities
   1.4 Continuous and Discrete System
   1.5 System Modeling
   1.6 Types of Models
   1.7 Principles of Modeling
   1.8 Area of application
   1.9 Verification and Validation of model

1.1 System Concept

System Concept

- The term system is derive 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 a broader definition of a system is, *"Any object which has some action to perform and is dependent on number of objects called entities, is a system".* For example a class room, a college, or a university is a system. University consists of number of colleges and a college has class rooms, students, laboratories and lot many other objects.
- Klir gives a collection of 24 definitions one such definition is "*A system is a collection of components wherein individual components are constrained by connecting interrelationships such that the system as a whole fulfills some specific functions in response to varying demands*".

Klir, George J. , An approach to general systems theory, New York: Van Nostrand Reinhold Co, 1969

System Concept

- The systems 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.

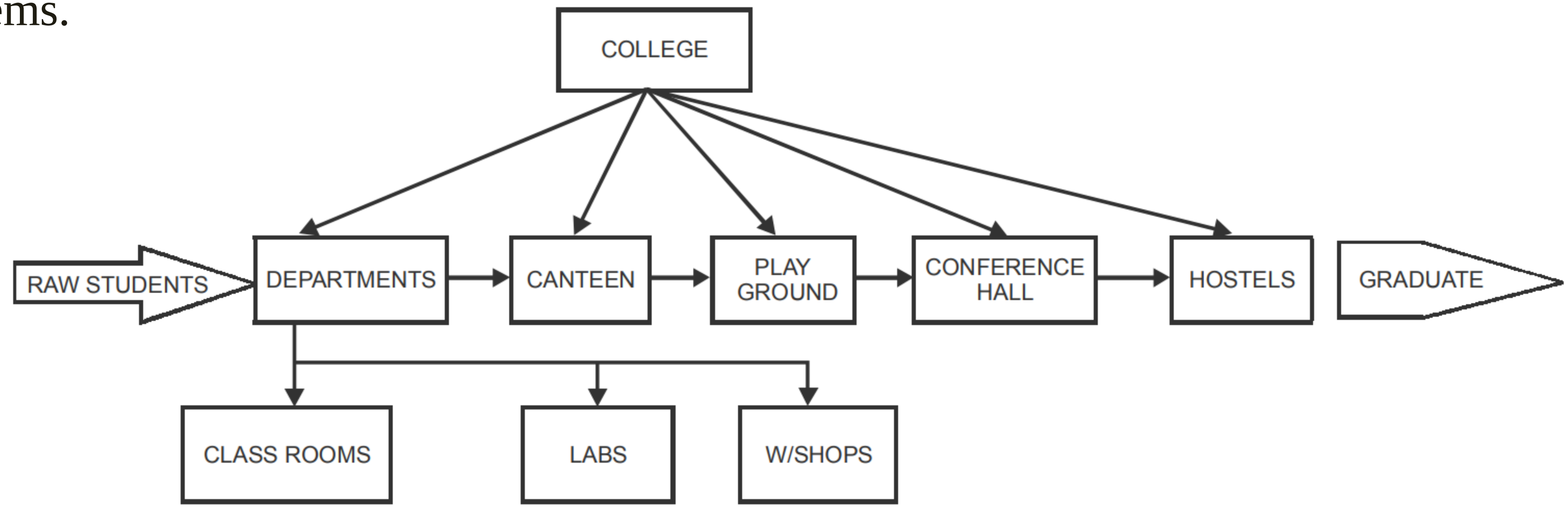


Fig: College as a system

System Concept

- As an example of a conceptually simple system (Geofrey Gordon, 2004), consider an aircraft flying under the control of an autopilot.
- A gyroscope in the autopilot detects the difference between the actual heading of aircraft and the desired heading. It sends a signal to move the control surfaces. In response to control surfaces movement, the aircraft steers towards the desired heading.

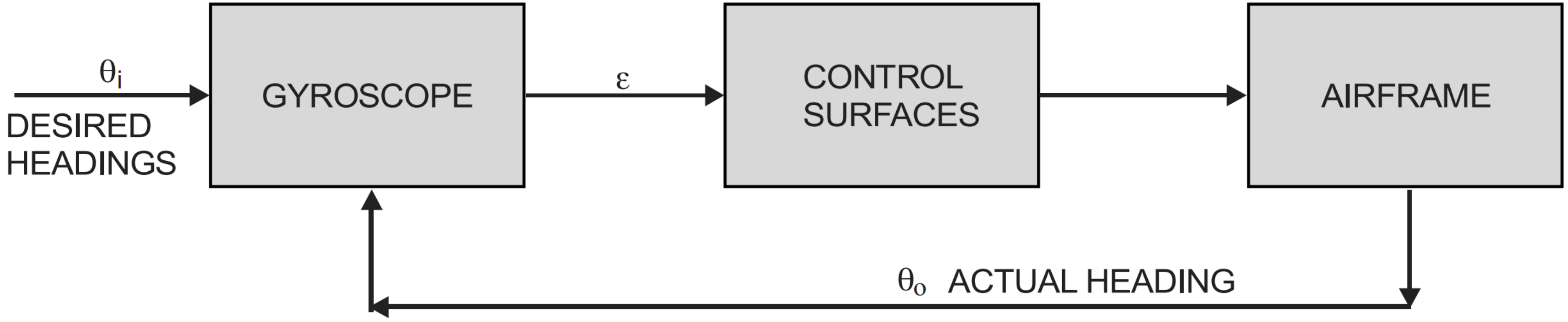


Fig. 0.2: *Model of an autopilot aircraft.*

Components of System

- Three basic components of system are Entity, Attributes, Activities.
- A term entity will be used to denote an object of interest in a system and the term attributes denotes its properties.
- A function to be performed by the entity is called its activity.
- For example, if system is a class in a school, then students are entities, books are their attributes and to study is their activity.

Entities

- are the fundamental building blocks or components that comprise the system
- can be physical objects, abstract concepts, or even individuals within a social system.
- interact with each other and with the environment to accomplish the system's objectives.

Components of System

Attributes

- are the characteristics or properties of the entities within the system.
- define the qualities, behaviors, or states of the entities and influence how they interact with each other and with the environment.
- include measurable quantities such as size, weight, temperature, as well as qualitative traits such as color, shape, or function.

Activities

- represent the processes, functions, or behaviors that entities engage in within the system.
- involve the transformation of inputs into outputs, the exchange of information or energy, and the accomplishment of specific tasks or goals.
- are often dynamic and can occur over time, contributing to the overall functioning and behavior of the system.
- activities can be Endogenous and Exogenous

Components of System

- Endogenous Activities
  - internal activities that originate within the system itself.
  - driven by the system's own dynamics, interactions, and feedback loops.
  - influenced by the entities and attributes within the system and the relationships among them.
- Exogenous Activities
  - originate from outside the system and have an impact on the system's behavior.
  - external to the system and may include inputs, disturbances, or influences from the environment.
  - can affect the system's state, dynamics, and evolution but are not directly controlled by the system itself.

Components of System

State of a system/state variables

- collection of variables necessary to describe a system at a particular time , relative to the objectives of a study.
- Example: 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.

System	*Entities*	*Attributes*	*Activities*
Banking	Customers	Maintaining accounts	Making deposits
Production unit	Machines, workers	Speed, capacity, break-down	Welding, manufacturing
College	Teachers, students	Education	Teaching, games
Petrol pump	Attendants	To supply petrol	Arrival and departure of vehicles

Components of System

Table 1.1 Examples of Systems and Components

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	Origination; 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

1.2 System Environment

System Environment

- A system is often affected by changes occurring outside the system. Such changes occurring outside the system are said to occur in the *system environment*.
- Deciding upon the boundary between the system and its environment is indeed a crucial step in modeling a system, as it helps to define what is included within the system and what is considered external to it.
- This boundary definition influences the scope of the system model and the factors considered in its analysis.
- **Exogenous Activities:** The term exogenous is used to describe the activities in the environment that affect the system. Exogenous activities influence the system from its external environment. Example: strikes in a university system.
- **Endogenous Activities:** The term endogenous is used to describe activities occurring within the system. These activities are driven by the internal dynamics and interactions of the system's components. Example: sports, cultural functions in a university system.

System Environment

- Based on these activities a system may be classified as open or closed system.
- **Open System**
  - A system that is affected by exogenous activities from its environment is classified as an open system.
  - Open systems interact with and are influenced by their environment, exchanging energy, matter, and information across their boundaries.
- **Closed System**
  - A system with no exogenous activities, meaning it is not influenced by external factors, is classified as a closed system.
  - Closed systems do not exchange matter or energy with their environment; instead, they operate based on internal processes and interactions.

1.3 Stochastic Activities

1.3 Stochastic Activities

- Activities can be classified as deterministic or stochastic.

Deterministic Activities

- the outcome is entirely predictable given the initial conditions and inputs
- There is no randomness or uncertainty involved in the process.
- The exact outcome of deterministic activities can be precisely determined based on known factors, equations, or rules governing the system.

Examples: simple mathematical calculations, classical mechanics problems (e.g., projectile motion), and many engineering design processes where the behavior of the system can be fully understood and predicted with certainty.

1.3 Stochastic Activities

Deterministic Activities

Characteristics:

- follow clear cause-and-effect relationships, where a specific set of inputs always leads to the same output.
- represented by deterministic models, which describe the system's behavior using deterministic equations or algorithms.
- common in systems with well-defined rules, regular patterns, and no inherent randomness or variability.

1.3 Stochastic Activities

Stochastic Activities

- the outcome is subject to randomness or uncertainty.
- Even with the same initial conditions and inputs, the outcome may vary each time the activity is performed. However, the random output can be often measured and described in the form of probability distribution.
- involve inherent variability in their outcomes due to random factors, chance events, or incomplete information about the system.

Examples: random walks, stock market fluctuations, weather forecasting, and radioactive decay. These processes exhibit variability and unpredictability in their outcomes due to the influence of random factors.

1.3 Stochastic Activities

Stochastic Activities

Characteristics

- do not have a single, predictable outcome; instead, they are described by probability distributions that represent the range of possible outcomes and their likelihoods.
- often involve random variables and probabilistic models, where the behavior of the system is simulated or analyzed based on statistical principles.
- prevalent in systems affected by external influences, inherent randomness, or complex interactions where deterministic modeling may be insufficient to capture the full range of variability.

Aspect	Deterministic Activities	Stochastic Activities
Definition	Outcome is entirely predictable.	Outcome is subject to randomness or uncertainty.
Predictability	Exact outcome can be determined given initial conditions and inputs.	Outcome may vary each time the activity is performed.
Examples	Simple mathematical calculations, classical mechanics problems, engineering design processes.	Random walks, stock market fluctuations, weather forecasting, radioactive decay.
Characteristics	Follow clear cause-and-effect relationships.	Do not have a single, predictable outcome.
Representation	Often described by deterministic models using equations or algorithms.	Described by probability distributions and statistical models.
Variability	No variability; outcomes are consistent.	Inherent variability due to random factors.
Cause of Variability	N/A	Random factors, chance events, or incomplete information.
Common Fields	Engineering, physics, deterministic systems.	Finance, biology, weather forecasting, stochastic systems.

1.4 Continuous and Discrete System

1.4 Continuous and Discrete System

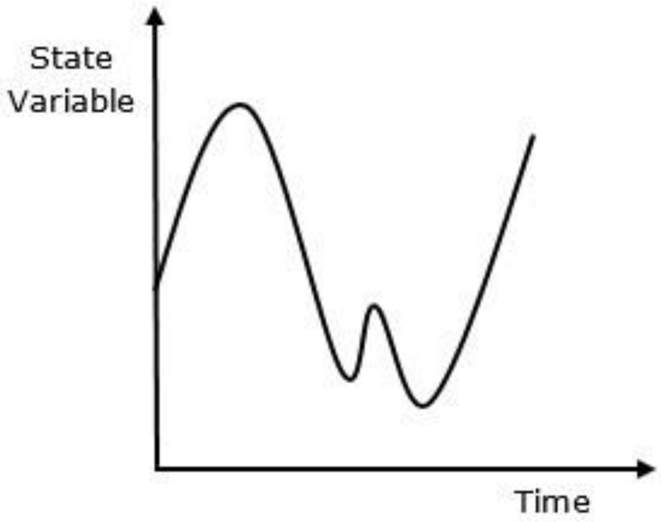
Continuous System

- A continuous system is a system where the *variables change continuously over time* or space. In other words, the system's state evolves smoothly, without sudden jumps or interruptions. For instance, movement of aircraft occurs smoothly.
- Continuous systems are typically modeled using continuous functions or differential equations. These equations describe the relationships between the system's variables and their rates of change.
- Time in continuous systems is treated as a continuous variable, meaning it can take on any value within a certain range.
- The system's behavior is observed and analyzed over a continuous range of time.
- Examples: physical systems such as fluid dynamics (e.g., fluid flow in pipes), analog electronics (e.g., electronic circuits with continuous signals), and population dynamics (e.g., continuous growth models).

1.4 Continuous and Discrete System

Continuous System

- Analytical methods such as calculus, Fourier analysis, and Laplace transforms are commonly used to analyze continuous systems. These methods enable the solution of differential equations and the study of system behavior over time.
- Continuous systems find applications in natural sciences (physics, chemistry, biology), engineering (mechanical, electrical, chemical), and other fields where processes evolve smoothly over time or space.



1.4 Continuous and Discrete System

Discrete System

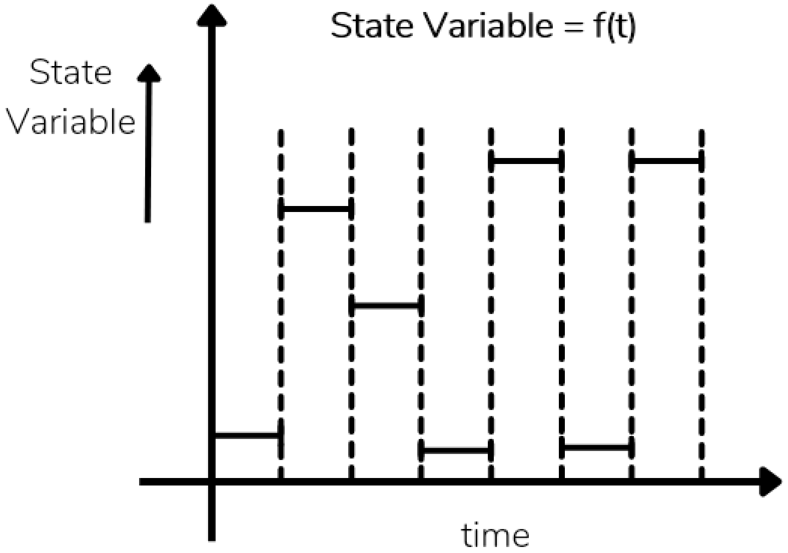
- A discrete system is a system where the *variables change at distinct time points or intervals*. The system's state evolves in discrete steps, with changes occurring only at specific instances in time.
- Discrete systems are typically modeled using discrete values or events. Variables are updated or changed incrementally at discrete time steps or intervals.
- Time in discrete systems is represented as a sequence of discrete time steps. The system's behavior is observed and analyzed at specific points in time rather than continuously.
- Examples: digital systems (e.g., digital circuits, computer algorithms), discrete event systems (e.g., queues, networks), and computer simulations with discrete time steps.

1.4 Continuous and Discrete System

Discrete System

- Discrete techniques such as difference equations, finite difference methods, and discrete-event simulation are used to analyze discrete systems. These methods focus on the discrete changes in variables over time.

- Discrete systems are widely used in computer science, digital signal processing, telecommunications, control systems, and many other fields where processes are inherently discrete or can be approximated as discrete



1.5 System Modeling

1.5 System Modeling

- A **model** is a *simplified representation of a system* at some particular point in time or space intended to promote understanding of the real system.
- In other words, we define a model as the body of information about the system gathered for the purpose of studying the system.
- Since the purpose of the study will determine the nature of the information that is gathered, there is no unique model of a system. Different models of the system will be produced by different system analysist who are interested in different aspects of the system.
- System modeling as the body of information about a system gathered for the purpose of studying the system.
- The tasks of deriving a system model are divided into two subtasks. They are
  1. Establishing the model structure
  2. Supplying the data

1.5 System Modeling

Establishing the Model Structure: This involves defining the structure of the system model, which includes determining its boundaries and identifying the fundamental components: entities, attributes, and activities. Defining the system boundary involves specifying what is included within the system and what lies outside of it. This boundary helps in focusing the analysis on the relevant components and interactions.

Supplying the Data: This involves providing the necessary data to populate the system model, including values for attributes and defining relationships between activities.

- Attribute Values: Data provides the values that attributes can have. This includes numerical values, categorical labels, or other forms of information that describe the characteristics of entities within the system.

- Relationships: Data also defines the relationships involved in the activities of the system. These relationships describe how entities interact with each other and with the environment to accomplish tasks or achieve objectives.

1.5 System Modeling

Example: A Vending Machine

Establishing the Model Structure

- System Boundary: The vending machine itself, including its components and operations, is within the system boundary.
- Entities: Vending machine, Products (e.g., snacks, beverages), Coins or currency
- Attributes: Vending machine attributes (capacity, inventory levels, prices of products), Product attributes(type, quantity, price), Coin attributes (denomination, quantity)
- Activities: Selecting a product, Inserting coins, Dispensing products, Returning change (if applicable)

1.5 System Modeling

Example: A Vending Machine

Supplying the Data

- Attribute Values: Vending machine capacity (maximum number of products it can hold), Inventory levels of each product, Prices of products, Denominations and quantities of coins accepted by the vending machine
- Relationships:
  - Users select products and insert coins to initiate the vending process
  - The vending machine verifies payment and dispenses the selected product
  - If payment exceeds the product price, the machine returns change

1.6 Types of Models

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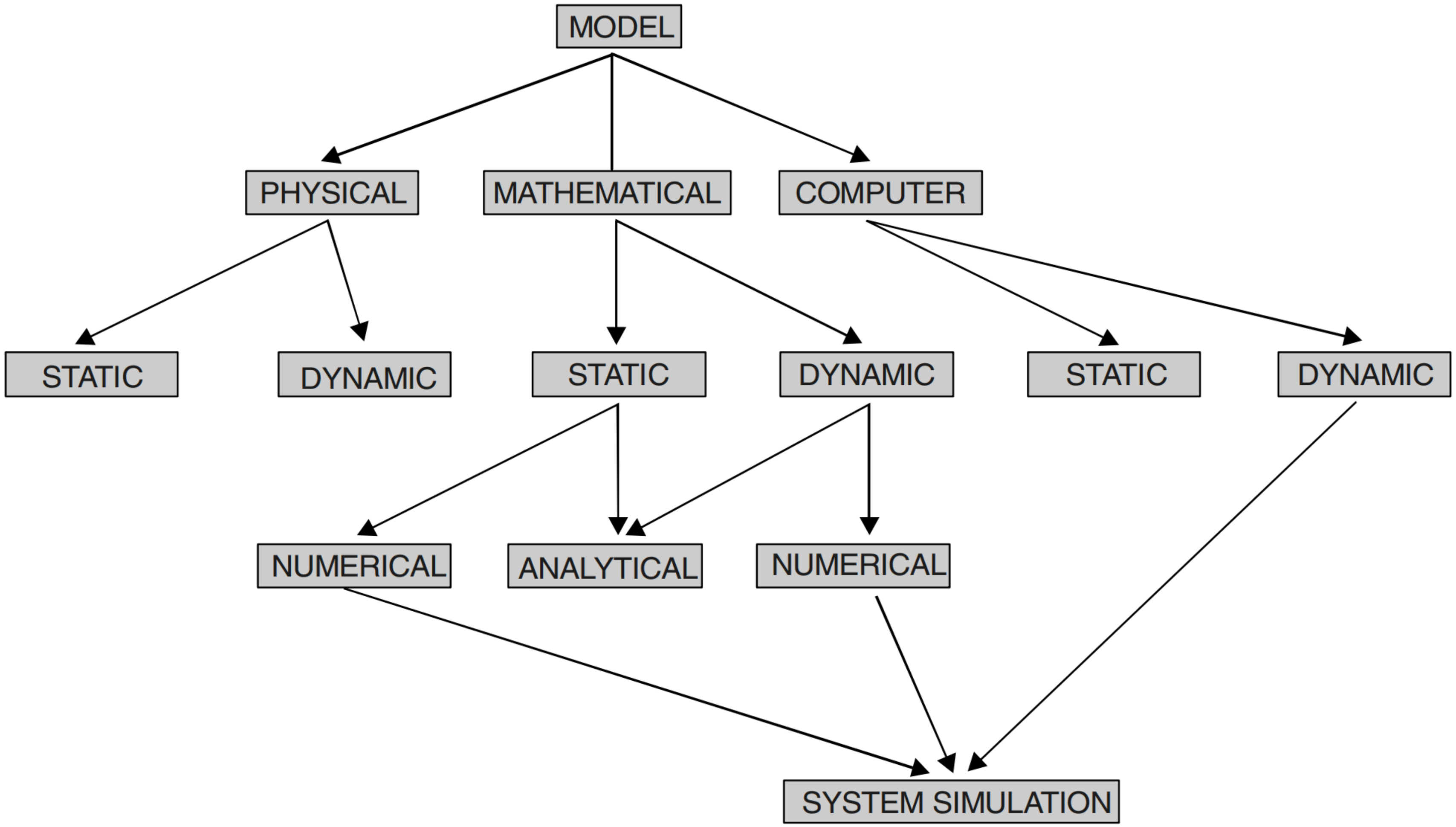


Fig. 1.1: *Different types of models.*

Physical Model

- Physical models are *based on some analogy between systems* such as mechanical and electrical or electrical or hydraulic.
- In physical model, the system attributes are represented by such measurements as voltage or the position of a shaft.
- The system activities are reflected in the physical laws that derive the models.
- **Example:** The rate at which the shaft of a direct current motor turns depends upon the voltage applied to the motor. If the applied voltage is used to represent the velocity of a vehicle, then the no. of revolutions of the shaft is a measure of the distance the vehicle has travelled.
- The higher the voltage, or velocity, the greater is the buildup of revolutions, or distance covered , in a given time.
- Physical models are of two types, static and dynamic.

Physical Model

- Static physical model is a scaled down model of a system which does not change with time.
  - An architect before constructing a building, makes a scaled down model of the building, which reflects all it rooms, outer design and other important features. This is an example of static physical model.
  - Similarly for conducting trials in water, we make small water tanks, which are replica of sea, and fire small scaled down shells in them. This tank can be treated as a static physical model of ocean.
- Dynamic physical models are ones which change with time or which are function of time.
  - In wind tunnel, small aircraft models (static models) are kept and air is blown over them with different velocities and pressure profiles are measured with the help of transducers embedded in the model. Here wind velocity changes with time and is an example of dynamic physical model.
  - A model of a hanging wheel of vehicle is another case of dynamic physical model discussed further.

Mathematical Model

- The mathematical model use symbolic notations and mathematical equations to represent a system.
- The system attributes are represented by variables and the activities that represented by mathematical functions that interrelate the variables.
- A second distinction is between static models and dynamic models. Static models can only show the values that system attributes take where the system is in balanced. Dynamic models follow the changes over time that result from system activities.
- In case of mathematical model the third distinction is a technique by which the model is solved that is actual values are assigned to system attributes.
- A distinction is made between analytical and numerical method. Applying analytical techniques means using the deductive reasoning of mathematical theory to solve a model. Example: linear differential method Numerical methods involve applying computational procedure to solve equations. Any assignment of numerical values that uses mathematical tables involves numerical methods.

Static Physical Model

- The best known examples of physical models are scale models.
- They are used in ship buildings to determine the exact measurements of plates covering the hull, deciphering of DNA molecules, Wind Tunnels and Water Tanks in the course of designing air craft or ships.
- They are also used for solving equations with particular boundary condition. For example, the flow of heat and distribution of electric charge through space can be related by common equation.
- In general, these equations can only be solved for simple-shaped bodies. In practice, solutions are needed for specific, complicated shapes.
- The distribution of heat in a body can be predicted by enclosing a space that has the same shape as the body, and measuring the charge in the space when the surface of the space has been electrified in a manner that reflects the way heat will be injected in the body.

Dynamic Physical Model

- They rely upon an analogy between the system being studied and some other system of a different nature.

- Consider a wheel of mass M, suspended in vertical direction, a force F(t), which varies with time, is acting on it. Mass is connected with a spring of stiffness K, and a piston with damping factor D. When force F(t), is applied, mass M oscillates under the action of these three forces. This model can be used to study the oscillations in a motor wheel. Figure 1.2 shows such a system.

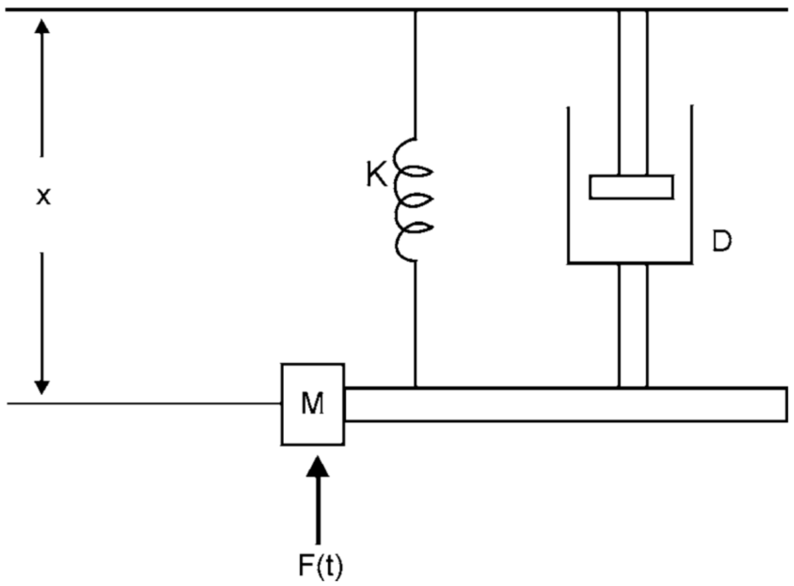


Fig. 1.2: *Suspended weight attached with spring and piston.*

- This is a discrete physical static model. Discrete in a sense, that one can give discrete values F and observe the oscillations of wheel with some measuring equipment. When force is applied on it, which is a function of time, this discrete physical static model becomes dynamic model. Parameters K and D can also be adjusted in order to get controlled oscillations of the wheel. This type of system is called spring-mass system. Load on the beams of a building can be studied by the combination of spring mass system.

Dynamic Physical Model

- Let us consider another static physical model which represents an electric circuit with an inductance L, a resistance R, and a capacitance C, connected with a voltage source which varies with time, denoted by the function E(t). This model is meant for the study of rate of flow of current as E(t) varies with time. Let q be the charge on the capacitance.
- There is some similarity between this model and model of hanging wheel. These physical models can easily be translated into a mathematical model.
- Let us construct mathematical model of system describing hanging wheel. Using Newton's second law of motions, system for wheel model can be expressed in the mathematical form.

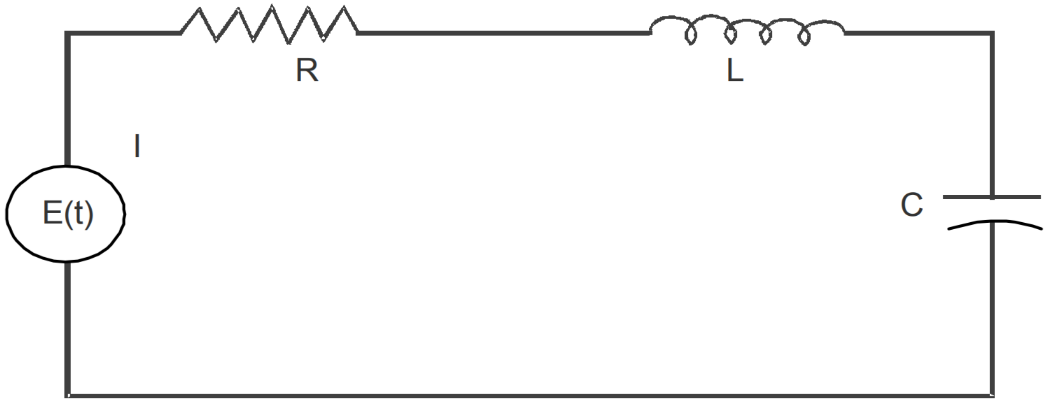


Fig. 1.3: *Static circuit of an electrical system.*

$$M\frac{d^2x}{dt^2} + D\frac{dx}{dt} + Kx = KF(t)$$

$$L\ddot{q} + R\dot{q} + \frac{q}{C} = \frac{E(t)}{C}$$

Dynamic Physical Model

MECHANICAL SYSTEM	ELECTRICAL SYSTEM
Mass (M)	Inductance (L)
Damping Factor (D)	Resistance (R)
Spring Constant (K)	Capacitance (1/C)
Force F(t)	Applied Voltage E(t)
Displacement (x)	Charge (q)
Velocity ($\dot{x}$)	Current ($\dot{q}$)
Acceleration ($\ddot{x}$)	Voltage ($\ddot{q}$)

$$M\frac{d^2x}{dt^2} + D\frac{dx}{dt} + Kx = KF(t)$$

$$L\ddot{q} + R\dot{q} + \frac{q}{C} = \frac{E(t)}{C}$$

- The mechanical system and the electrical system are analogs of each other, and the performance of either can be studied with the other.
- In practice, it is simpler to modify the electrical system than to change the mechanical system, so it is more likely that the electrical system will have been built to study the mechanical system.

Static Mathematical Models

- If mathematical model does not involve time i.e., system does not change with time, it is called a static mathematical model of the system.
- A static model gives the relationship between the system attributes when the system is in equilibrium.
- If the point of equilibrium is changed by altering any of the attribute values, the model enables the new values for all the attributes to be derived but does not show the way in which they changed to their new values.
- **Example:** In marketing a commodity there is a balance between the supply and demand for the commodity. Both factor (demand and supply) depend upon price.
  - **The law of supply:** the quantity of a good supplied rises as the market price rises, and falls as the price falls.
  - **The law of demand:** the quantity of a good demanded falls as the price rises, and vice versa.

Static Mathematical Models

- Since the relationship have been assumed linear, the complete market model can be written mathematically as,

  $D = a - bP$ and

  $S = c + dP$

  where D is demand and S is supply.

- This can be solved analytically. In the equilibrium market price,

$$D = S \ \ i.e \ \ P = \frac{a - c}{b + d}$$

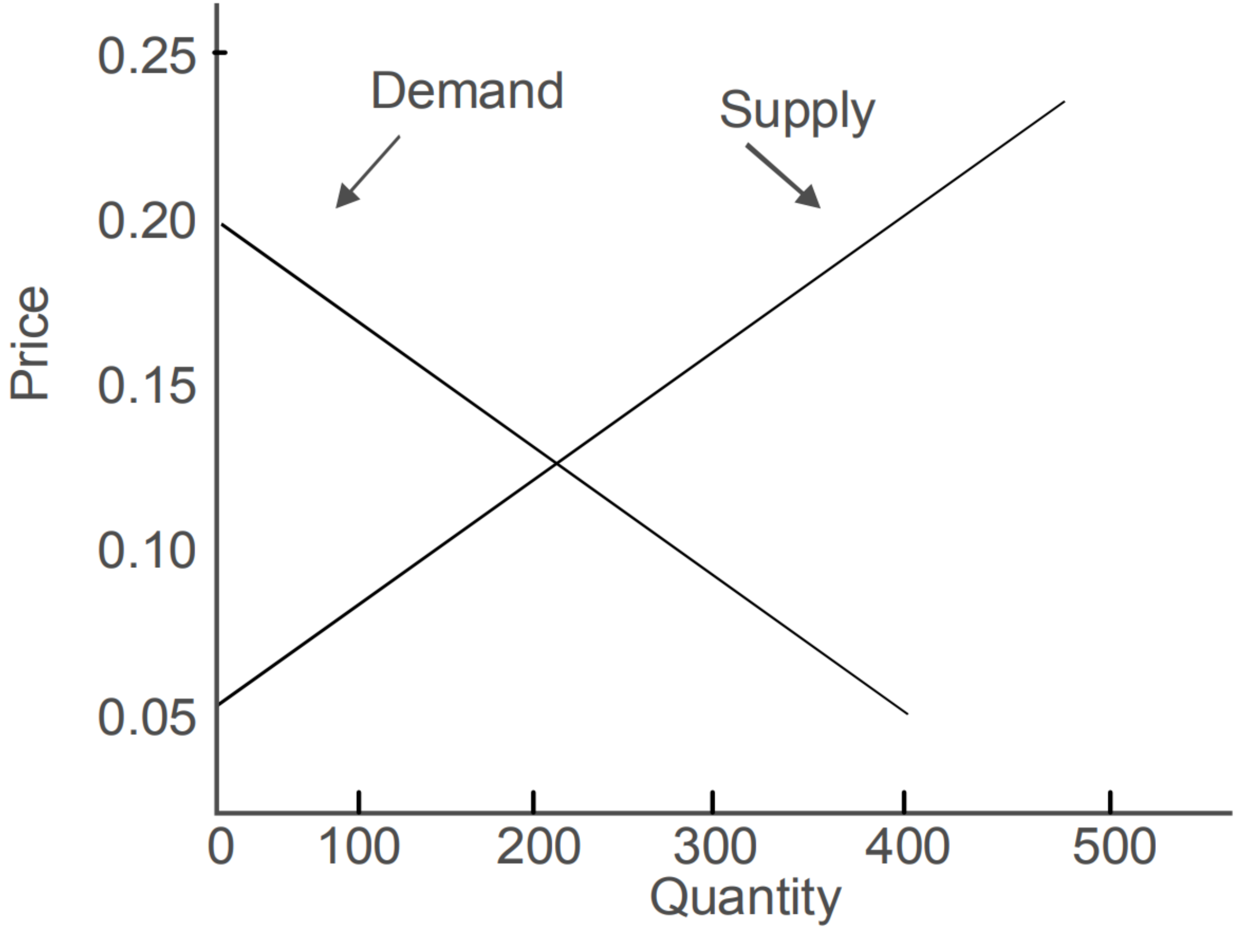


Fig. 1.4: *Market model.*

Static Mathematical Models

- Usually, the demand will be represented by a curve that slopes downwards, and the supply by a curve that slopes upwards, as illustrated in Figure
- It may not then be possible to express the relationships by equations that can be solved. Some numeric method is then needed to solve the equations.
- Drawing the curves to scale and determining graphically where they intersect is one such method. In practice, it is difficult to get precise values for the coefficients of the model.
- Observations over an extended period of time, however, will establish the slopes (that is, the values of b and d) in the neighborhood of the equilibrium point, and, of course, actual experience will have established equilibrium prices under various conditions.

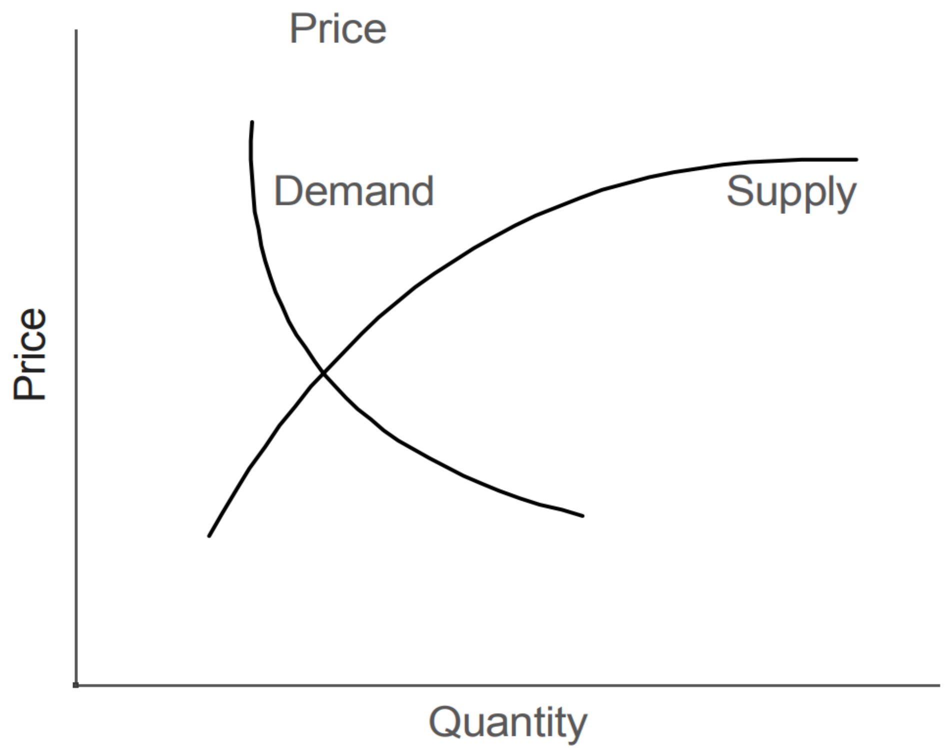


Fig. 1.5: *Non-linear market model.*

Dynamic Mathematical Model

- A dynamic mathematical model allows the changes of system attributes to be derived as a function of time. The derivation may be made with an analytical solution or with a numerical computation depending upon the with a numerical computation, depending upon the complexity of the model.

- The equation that was derived to describe the behavior of a wheel suspension of a vehicle is an example of a dynamic mathematical model; in this case, an equation that can be solved analytically.

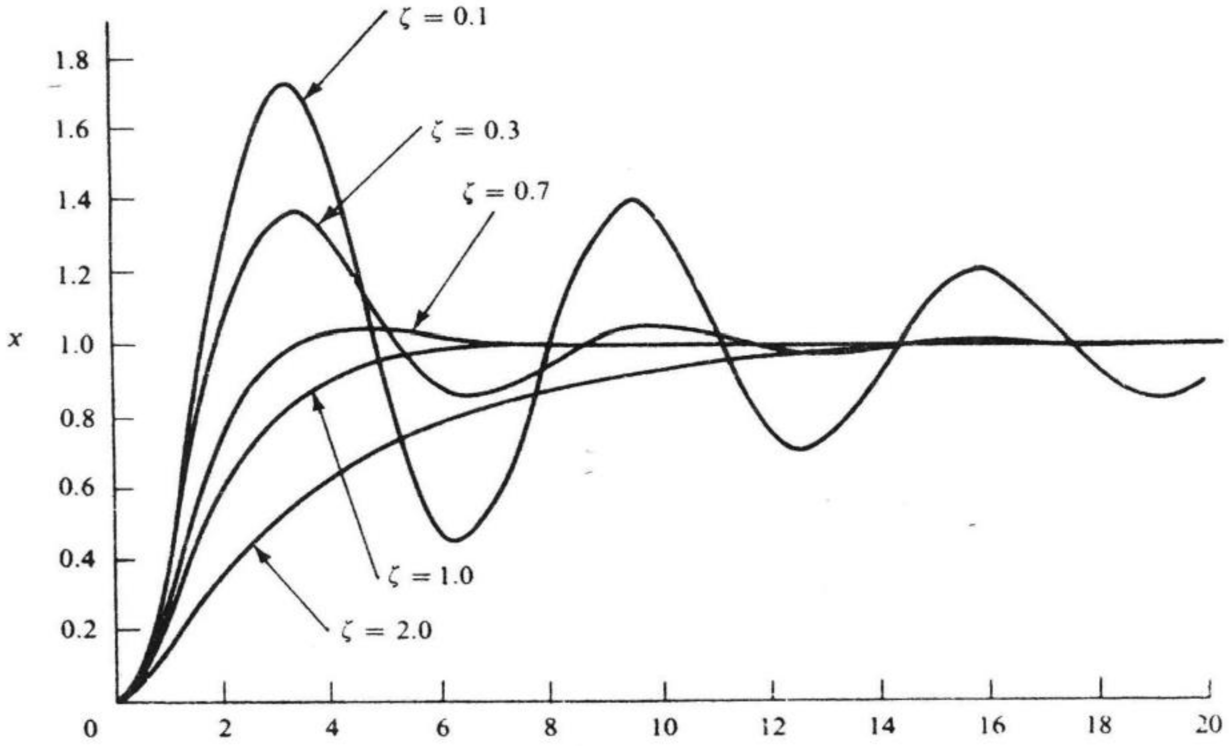
$$M\frac{d^2x}{dt^2} + D\frac{dx}{dt} + Kx = KF(t) \Longrightarrow \ddot{x} + 2\varsigma\omega\dot{x} + \omega^2 x = \omega^2 f(x)$$

Where $2\varsigma\omega$ =D/M and ω^2 =K/M

- The factor ς is called the damping ratio, and when the motion is oscillatory, the frequency of oscillation is determined from the formula $\omega = 2\pi f$ where f is the number of cycles per second.

Dynamic Mathematical Model

- Figure shows how x varies in response to a steady force applied at time t = 0 as would occur for instance, if a load were suddenly placed on the automobile.
- Solutions are shown for several values of ζ , and it can be seen that when ζ is less than 1, the motion is oscillatory.



1.7 Principles of Modeling

1.7 Principles of Modeling

5 Basic Principles of Modeling

a) Block Building

The description of the system should be organized in a series of block. The aim is to simplify the specification of the interaction with in a system. Block building refers to the process of constructing the model by breaking down the system into manageable blocks or components. Each block represents a distinct aspect or function of the system, making the overall model easier to understand and analyze. By building the model in blocks, it becomes easier to identify relationships between components and to make changes or modifications to specific parts of the system without affecting the entire model.

b) Relevance

Relevance emphasizes the importance of including only relevant factors and variables in the model. Extraneous details or irrelevant components can clutter the model and make it more complex than necessary. It's essential to focus on capturing the essential aspects of the system that are directly related to the objectives of the analysis or simulation.

1.7 Principles of Modeling

5 Basic Principles of Modeling

c) Accuracy

Accuracy involves ensuring that the model accurately represents the real-world system it is intended to simulate or analyze. The model should reflect the actual behavior, relationships, and dynamics of the system as closely as possible. This requires careful selection of input data, appropriate modeling techniques, and validation against empirical observations or data.

d) Aggregation

Aggregation involves simplifying the model by combining or summarizing similar components or variables. Aggregating similar elements reduces complexity and computational burden while still capturing the essential characteristics of the system. However, it's important to strike a balance between aggregation and accuracy to ensure that important details are not overlooked.

1.7 Principles of Modeling

5 Basic Principles of Modeling

e) Validation

Validation is the process of confirming that the model produces reliable and credible results. Validation involves comparing the model's predictions or simulations against real-world data or observations. If the model accurately replicates the behavior of the system and produces results that align with empirical evidence, it is considered validated and can be used with confidence for analysis or decision-making.

Example

A model of a system can be divided into number of blocks, which in itself are complete systems. But these blocks should have some relevance to main system. For example, let us take an example of a school. Class rooms are blocks of the school. Aim of the school is to impart education to students and class rooms are required for the coaching. Thus relevance of class rooms (blocks) with school is coaching.

1.7 Principles of Modeling

- Interdependency is the one of the important factor of different blocks. Each block should be accurate and tested independently. Then these blocks are to be integrated together. Last is the validation i.e., this model is to be tested for its performance.
- For validation following methods can be used.
  - If the model is mathematical model, then some trivial results can be run for verifications.
  - If experimental results are available, model can be checked with these experimental results.

1.8 Application Areas of Simulation

What is Simulation ?

- Simulation is an experimental technique. It is a fast and experimental method of doing an experiment under computer. There is no specific unifying theory of computer simulation and no principle guiding the formulation of simulation model. Simulation provides an alternative that is cheap and fast and fills the gap between exact analysis and physical intuition.
- 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.
- In another word simulation is an imitation of the reality. Simulation has long been used by the researchers, analysts, designers and other professionals in the physical and non-physical experimentations and investigations.
- Naylor et al. defines the simulation as follows:

Simulation is a numerical technique for conducting experiments on a digital computer, which involves certain types of mathematical and logical models over extended period of real time.

Why Simulation Required?

According to Naylor, some of the reasons why simulation is appropriate are:

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 insight into which variables are the most important and into how variables interact.
5. Simulation can be used as a pedagogical device to reinforce analytic solution methodologies.
6. Simulation can be used to experiment with new designs or policies before implementation, so as to prepare for what might happen.

Why Simulation Required?

7. Simulation can be used to verify analytic solutions.
8. Simulating different capabilities for a machine can help determine the requirements on it.
9. Simulation models designed for training make learning possible without the cost and disruption of on-the-job instruction.
10. Animation shows a system in simulated operation so that the plan can be visualized.
11. The modem system (factory, wafer fabrication plant, service organization, etc.) is so complex that its internal interactions can be treated only through simulation.

Naylor, TJ, Balintfy, JL, Burdick, DS, and K Chu, Computer Simulation Techniques, Wiley, NY, 1966.

When to use Simulation ?

- Over the years tremendous developments have taken place in computing capabilities and in special purpose simulation languages, and in simulation methodologies. The use of simulation techniques has also become widespread.
- Following are some of the purposes for which simulation may be used.
  - Simulation is very useful for experiments with the internal interactions of a complex system, or of a subsystem within a complex system.
  - Simulation can be employed to experiment with new designs and policies, before implementing
  - Simulation can be used to verify the results obtained by analytical methods and reinforce the analytical techniques.
  - Simulation is very useful in determining the influence of changes in input variables on the output of the system.
  - Simulation helps in suggesting modifications in the system under investigation for its optimal performance.

When Simulation Is Not Appropriate ?

- This section is based on an article by Banks and Gibson [1997], who gave ten rules for evaluating when simulation is not appropriate.
- The first rule indicates that simulation *should not be used when the problem can be solved by common sense*. An example is given of an automobile tag facility serving customers who arrive randomly at an average rate of 100/hour and are served at a mean rate of 12/hour. To determine the minimum number of servers needed, simulation is not necessary. Just compute 100/12 = 8.33 indicating that nine or more servers are needed.
- The second rule says that simulation *should not be used if the problem can be solved analytically*. For example, under certain conditions, the average waiting time in the example above can be found from curves that were developed by Hillier and Lieberman [2015].

When Simulation Is Not Appropriate ?

- The third rule says that simulation *should not be used if it is easier to perform direct experiments*. An example of a fast-food drive-in restaurant is given where it was less expensive to stage a person taking orders using a hand-held terminal and voice communication to determine the effect of adding another order station on customer waiting time.

- The fourth rule says *not to use simulation if the costs exceed the savings*. There are many steps in completing a simulation, and these must be done thoroughly. If a simulation study costs $20,000 and the savings might be $10,000, simulation would not be appropriate.

- Rules five and six indicate that *simulation should not be performed if the resources or time are not available*. If the simulation is estimated to cost $20,000 and there is only $10,000 available, the suggestion is not to venture into a simulation study. Similarly, if a decision in needed in two weeks and a simulation will take a month, the simulation study is not advised. Simulation takes data, sometimes lots of data. If no data is available, not even estimates, simulation is not advised.

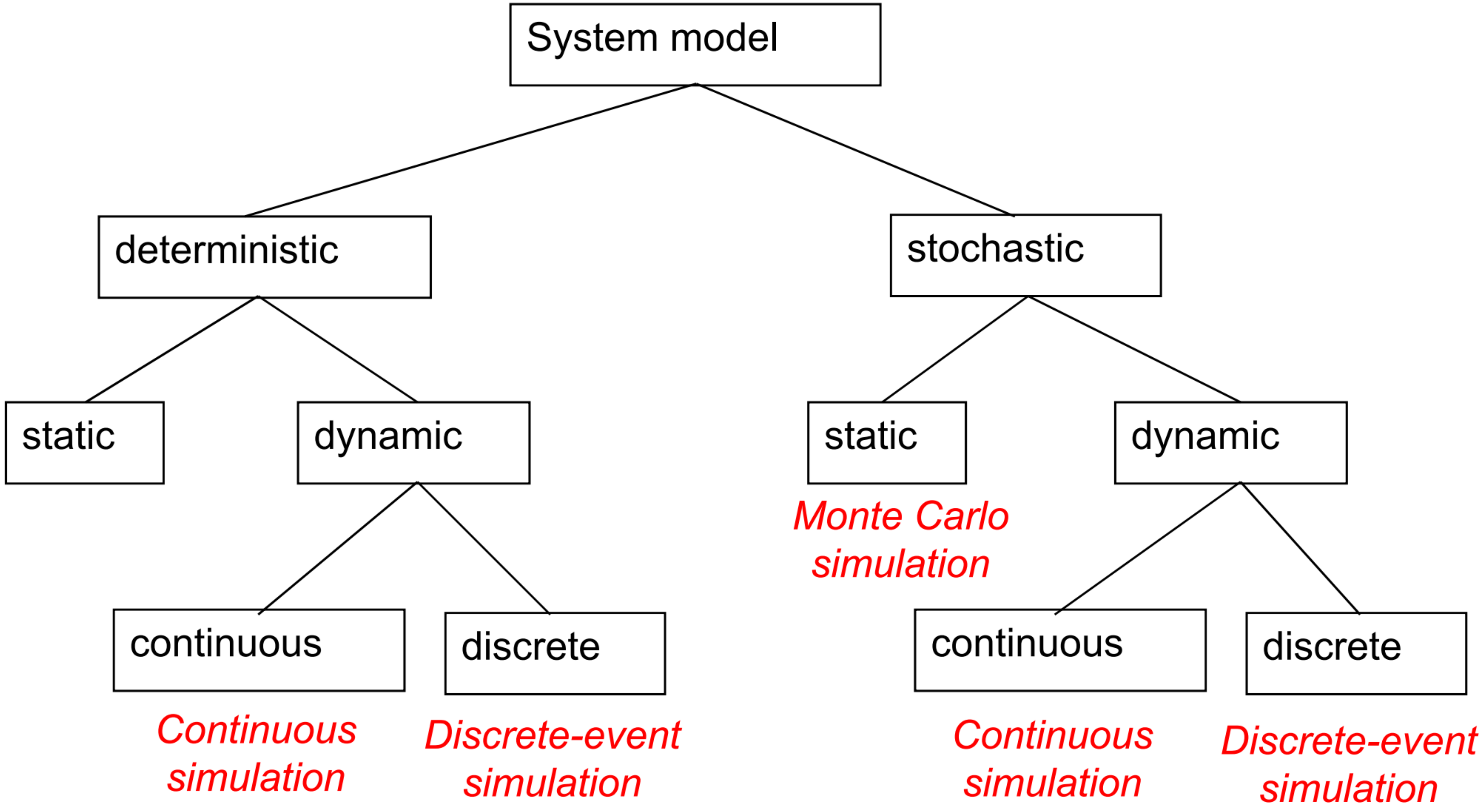
When Simulation Is Not Appropriate ?

- The next rule concerns the ability to verify and validate the model. If there is *not enough time or if the personnel are not available, simulation is not appropriate*.
- If managers have unreasonable expectations, if they ask for too much too soon, or if the power of simulation is overestimated, simulation might not be appropriate.
- Last, if system behavior is too complex or can't be defined, simulation is not appropriate. Human behavior is sometimes extremely complex to model.

Banks, J., & Gibson, R. (1997). 10 rules for determining when simulation is not appropriate. *IIE Solutions*, *29*(9).

Hillier, F. S., & Lieberman, G. J. (2015). Introduction to operations research. McGraw-Hill.

Types of Simulation Models



1.8 Application Areas of Simulation

- **Manufacturing and Logistics**
  - Simulation is used to optimize production processes, layout design, and scheduling in manufacturing facilities.
  - It helps in simulating supply chain networks to improve efficiency, reduce costs, and manage inventory levels effectively.
- **Healthcare**
  - In healthcare, simulation is employed for training medical professionals in surgical procedures, patient care, and emergency response scenarios.
  - It's used to model patient flows in hospitals, assess the impact of resource allocation strategies, and optimize healthcare delivery systems.

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- **Transportation and Urban Planning**
  - Simulation is utilized for traffic management, urban mobility planning, and infrastructure design. It helps in assessing the performance of transportation systems, modeling traffic flow, and evaluating the effectiveness of public transit services.
- **Finance and Business**
  - Simulation is applied in financial risk management, portfolio optimization, and investment analysis. It aids in modeling stock market behavior, simulating economic scenarios, and assessing the impact of business decisions on financial performance.
- **Environmental Science and Engineering**
  - Simulation is used to model environmental processes, such as climate change, air and water quality, and ecosystem dynamics. It helps in designing and optimizing environmental remediation strategies, assessing the impact of pollution sources, and predicting natural disasters.

1.8 Application Areas of Simulation

- **Defense and Security**
  - Simulation is employed for military training, mission planning, and scenario analysis. It aids in modeling battlefield scenarios, assessing the effectiveness of defense systems, and evaluating security protocols.
- **Education and Training**
  - Simulation is used for educational purposes, such as interactive learning environments, virtual laboratories, and simulation-based assessments. It helps in training personnel across various industries, including aviation, engineering, and emergency services.
- **Entertainment and Gaming**
  - Simulation is prevalent in the entertainment industry for creating immersive experiences, virtual worlds, and realistic simulations. It's used in gaming for developing simulations of sports, strategy, and role-playing games, providing engaging and interactive experiences for players.

1.9 Verification and Validation of Model

1.9 Verification and Validation of Model

Verification

- the process of ensuring that the model is implemented correctly and operates as intended according to its specifications and requirements. Did I build the model right?
- **Activities**
  - Checking the model code or implementation against its design specifications to identify errors or discrepancies.
  - Conducting unit tests to verify individual components or modules of the model.
  - Performing code reviews and inspections to identify coding errors, logic flaws, or inconsistencies.
  - Using automated testing tools and techniques to detect errors and ensure consistency in the model implementation.
- **Purpose:** Verification aims to confirm that the model accurately represents the conceptual design and follows the intended behavior as specified by the requirements. It focuses on identifying and correcting errors in the model implementation to improve its quality and reliability.

1.9 Verification and Validation of Model

Validation

- Validation is the process of assessing whether the model accurately represents the real-world system it is intended to simulate or analyze. Did I build the right model?
- **Activities**
  - Comparing the model's predictions or outputs with empirical data, experimental results, or observations from the real system.
  - Conducting sensitivity analyses to evaluate the model's response to changes in input parameters or assumptions.
  - Performing uncertainty analyses to quantify and understand the uncertainties and limitations of the model predictions.
  - Validating the model against known benchmarks or established standards in the field.

1.9 Verification and Validation of Model

Validation

- **Purpose:** Validation aims to assess the model's credibility and reliability by confirming that it produces accurate and meaningful results consistent with real-world observations. It provides confidence in the model's ability to support decision-making and its suitability for its intended application.
- Verification and validation are iterative processes that are often conducted in parallel throughout the model development lifecycle.

Project Assignment

- Study one of the following paper and implement this in Python programming Language.

1. Rodecap, S. E., & Lindstrom, F. T. (1976). Numerical simulation of a compartmental system for the distribution of lipid soluble chemicals in mammalian tissues. *Computers in Biology and Medicine*, *6*(1), 33-51.

2. Yadav, R. P., & Verma, R. (2020). A numerical simulation of fractional order mathematical modeling of COVID-19 disease in case of Wuhan China. *Chaos, Solitons & Fractals*, *140*, 110124.