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MS Notes.

to the former, when we are equally concerned about the internal details of the system and its processes besides the input and output variable, such an approach of system is considered as white box. For example, when we model a city as a pollution production system, regardless of which chimney emitted a particular plume of smoke, it is sufficient to know the total amount of fuel that enters the city to estimate the total amount of carbon dioxide and other gases produced. The "black box" view of the city will be much simpler and easier to use for the calculation of overall pollution levels than the more detailed "white box" view, where we trace the movement of every fuel tank to every particular building in the city.

The system as a whole is more than the sum of its parts. For example, if person A alone is too short to reach an apple on a tree and person B is too short as well, once person B sits on the shoulders of person A, they are more than tall enough to reach the apple. In this example, the product of their synergy would be one apple. Another case would be two politicians. If each is able to gather 1 million votes on their own, but together they were able to appeal to 2.5 million voters, their synergy would have produced 500,000 more votes than had they each worked independently.

1.2 Classification of Systems

Systems can be classified on the basis of time frame, type of measurements taken, type of interactions, nature, type of components, etc.

1.2.1 According to the Time Frame

Systems can be categorized on the basis of time frame as

- Discrete
- Continuous
- Hybrid

A *discrete* system is one in which the state variables change instantaneously at separated points in time, for example, queuing systems (bank, telephone network, traffic lights, machine breakdowns), card games, and cricket match. In a bank system, state variables are the number of customers in the bank, whose value changes only when a customer arrives or when a customer finishes being served and departs.

A *continuous* system is one in which the state variables change continuously with respect to time, for example, solar system, spread of pollutants, charging a battery. An airplane moving through the air is an example of a continuous system, since state variables such as position and velocity can change continuously with respect to time.

Few systems in practice are wholly discrete or wholly continuous, but since one type of change predominates for most systems, it will usually be possible to classify a system as being either discrete or continuous.

A *hybrid* system is a combination of continuous and discrete dynamic system behavior. A hybrid system has the benefit of encompassing a larger class of systems within its structure, allowing more flexibility in modeling continuous and discrete dynamic phenomena, for example, traffic along a road with traffic lights.

1.2.2 According to the Complexity of the System

Systems can be classified on the basis of complexity, as shown in Figure 1.3.

Physical systems
Conceptual systems
Esoteric systems

Physical systems can be defined as systems whose variables can be measured with physical devices that are quantitative such as electrical systems, mechanical systems, computer systems, hydraulic systems, thermal systems, or a combination of these systems. Physical system is a collection of components, in which each component has its own behavior, used for some purpose. These systems are relatively less complex. Some of the physical systems are shown in Figure 1.4a and b.

Conceptual systems are those systems in which all the measurements are conceptual or imaginary and in qualitative form as in psychological systems, social systems, health care systems, and economic systems. Figure 1.4c shows the transportation system. Conceptual systems are those systems in which the quantity of interest cannot be measured directly with physical devices. These are complex systems.

Esoteric systems are the systems in which the measurements are not possible with physical measuring devices. The complexity of these systems is of highest order.

1.2.3 According to the Interactions

Interactions may be unidirectional or bidirectional, crisp or fuzzy, static or dynamic, etc. Classification of systems also depends upon the degree of interconnection of events from

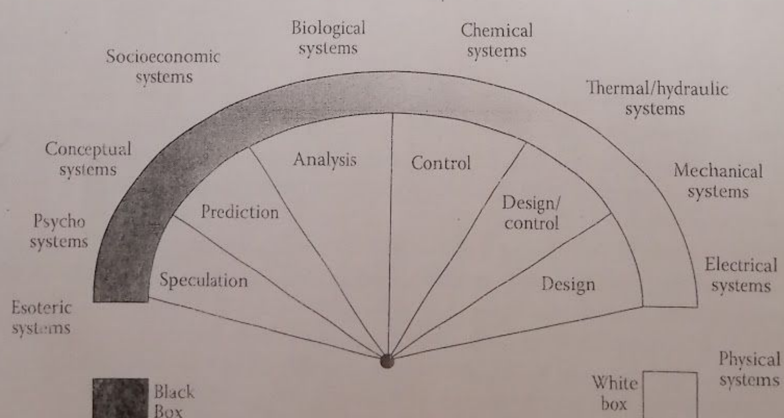


FIGURE 1.3
Classification of system based on complexity.

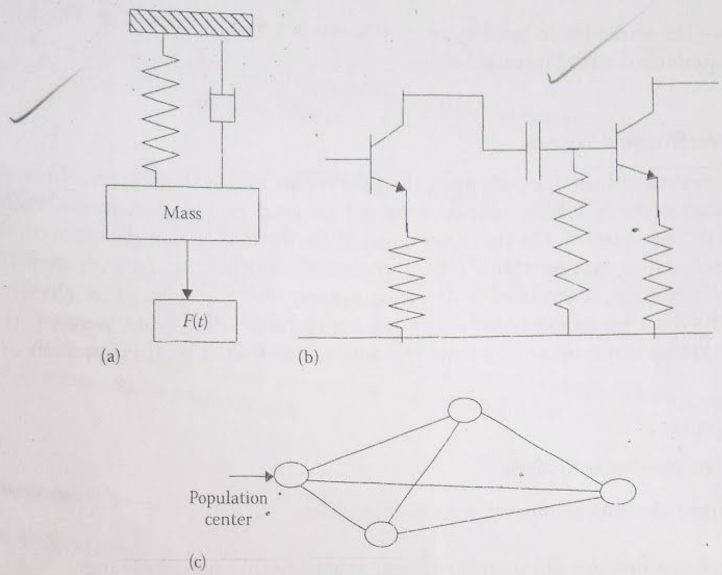


FIGURE 1.4
Different types of systems. (a) Mechanical system. (b) Electronic circuit. (c) Transportation system.

none to total. Systems will be divided into three classes according to the degree of interconnection of events.

1. *Independent*—If the events have no effect upon one another, then the system is classified as independent.
2. *Cascaded*—If the effects of the events are unilateral (that is, part A affects part B, B affects C, C affects D, and not vice versa), the system is classified as cascaded.
3. *Coupled*—If the events mutually affect each other, the system is classified as coupled.

1.2.4 According to the Nature and Type of Components

1. Static or dynamic components
2. Linear or nonlinear components
3. Time-invariant or time-variant components
4. Deterministic or stochastic components
5. Lumped parametric component or distributed parametric component
6. Continuous-time and discrete-time systems

1.2.5 According to the Uncertainties Involved

Deterministic—No uncertainty in any variables, for example, model of pendulum.

Stochastic—Some variables are random, for example, airplane in flight with random wind gusts, mineral-processing plant with random grade ore, and phone network with random arrival times and call lengths.

Fuzzy systems—The variables in such type of systems are fuzzy in nature. The fuzzy variables are quantified with linguistic terms.

1.2.5.1 Static vs. Dynamic Systems

Normally, the system output depends upon the past inputs and system states. However, there are certain systems whose output does not depend on the past inputs called static or memoryless systems. On the other hand, if the system output depends on the past inputs and earlier system states which essentially implied that the system has some memory elements, it is called a dynamic system. For example, if an electrical system contains inductor or capacitor elements, which have some finite memory, due to which the system response at any time instant is determined by their present and past inputs.

1.2.5.2 Linear vs. Nonlinear Systems

The study of linear systems is important for two reasons:

1. Majority of engineering situations are linear at least within specified range.
2. Exact solutions of behavior of linear systems can usually be found by standard techniques.

Except, a handful special types, there are no standard methods for analyzing nonlinear systems. Solving nonlinear problems practically involves graphical or experimental approaches. Approximations are often necessary, and each situation usually requires special handling. The present state of art is such that there is neither a standard technique which can be used to solve nonlinear problems exactly, nor is there any assurance that a good solution can be obtained at all for a given nonlinear system.

The *Ohm's law* governs the relation between the voltage across and the current through a resistor. It is a linear relationship because voltage across a resistor is linearly proportional to the current through it.

$$V \propto I$$

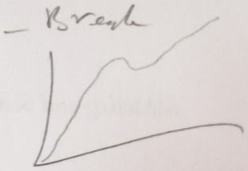
But even for this simple situation, the linear relationship does not hold good for all conditions. For instance, as the current in a resistor increases exceedingly, the value of its resistance will increase due to increase in temperature of the resistor:

$$R_t = R(1 + \alpha T)$$

The amount of change in resistance is being dependent upon the magnitude of the current, and it is no longer correct to say that the voltage across the resistor bears a linear relationship to current through it.

Similarly, the *Hooke's law* states that the stress is linearly proportional to the strain in a spring. But this linear relationship breaks down when the stress on the spring is too great. When the stress exceeds the elastic limit of the material of which the spring is made, stress

Elastic range – Plastic range – Break



and strain are no longer linearly related. The actual relationship is much more complicated than the Hooke's law situation, that is,

$$\text{Stress}(\sigma) \propto \text{Strain}(\varepsilon)$$ only in elastic region

Therefore, we can say that restrictions always exist for linear physical situation, saturation, breakdown, or material changes with ultimate set in and destroy linearity. Under ordinary circumstances physical conditions in many engineering problems stay well within the restrictions and the linear relationship holds good.

Ohm's law and Hooke's law describe only special linear systems. There exist systems that are much more complicated and are not conveniently described by simple voltage–current or stress–strain relationships.

1.3 Linear Systems

An engineer's interest in a physical situation is very frequently the determination of the

2.4 Classification of Models

Models have been widely accepted as a means for studying complex phenomena for experimental investigations at a lower cost and in less time, than trying changes in actual systems. Knowledge can be obtained more quickly, and for conditions not observable in real life. Models tell us about our ignorance and give better insights into the system. System models may be classified as shown in Figure 2.2.

2.4.1 Physical vs. Abstract Model

To most people, the word "model" evokes images of clay cars in wind tunnels, cockpits disconnected from their airplanes to be used in pilot training, or miniature supertankers scurrying about in a swimming pool. These are examples of physical models (also called iconic models), and are not typical of the kinds of models that are of interest in operations research and system analysis. Physical models are most easily understood. They are usually physical replicas, often on a reduced scale. Dynamic physical models are used as in wind tunnels to show the aerodynamic characteristics of proposed aircraft designs. Occasionally, however, it has been found useful to build physical models to study engineering or management systems; examples include tabletop scale models of material-handling systems, and in at least one case a full-scale physical model of a fast food restaurant inside a warehouse, complete with full-scale, and, presumably hungry humans. But the vast majority of models built for such purposes are abstracted,

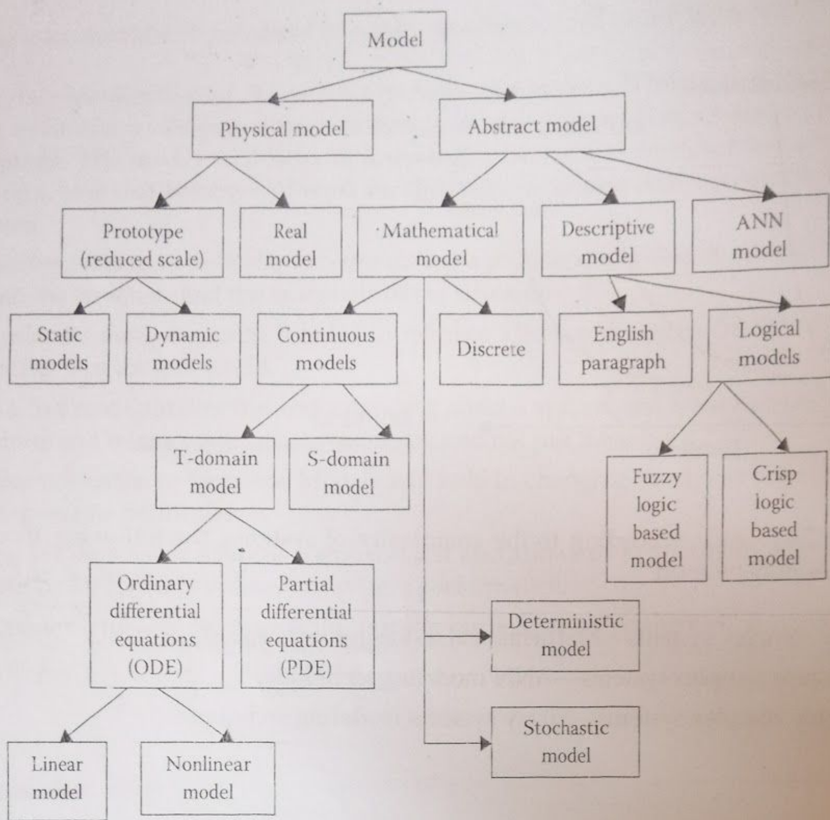


FIGURE 2.2
Pictorial representation of the classification of models.

representing a system in terms of logical or quantitative relationships that are then manipulated and changed to see how the model reacts, and thus, how the system would react—if the abstract model is a valid one. An abstract model is one in which symbols, rather than physical devices, constitute the model. The abstract model is more common but less recognized. The symbolism used can be a written language or a thought process.

2.4.2 Mathematical vs. Descriptive Model

A mathematical model is a special subdivision of abstract models. The mathematical model is written in the language of mathematical symbols. Perhaps the simplest example of an abstracted mathematical model is the familiar relation

$$\text{Distance} = \text{Acceleration} \times \text{Time}$$

$$d = a * t \tag{2.1}$$

This might provide a valid model in one instance (e.g., a space probe to another planet after it has attained its flight velocity) but a very poor model for other purposes (e.g., rush-hour commuting on congested urban freeways).

2.4.3 Static vs. Dynamic Model

Static models are quite common for architectural works to visualize the floor plane. A static simulation model is a representation of a system at a particular time, or one that may be used to represent a system in which time simply plays no role. On the other hand, a dynamic simulation model represents a system as it evolves over time, such as a conveyor system in a factory. A dynamic model deals with time-varying interactions.

2.4.4 Steady State vs. Transient Model

A steady state pattern is one that is representative with time and in which the behavior in one time period is of the same nature as any other period.

Transient behavior describes those changes where the system response changes with time. A system that exhibits growth would show transient behavior, as it is a "one-time" phenomena, and cannot be repeated.

2.4.5 Open vs. Feedback Model

The distinction is not as clear as the word suggests. Different degrees of openness can exist. The closed model is one that internally generates the values of variables through time by the interaction of variables one on another. The closed model can exhibit interesting and informative behavior without receiving an input variable from an external source. Information feed back systems are essentially closed systems.

2.4.6 Deterministic vs. Stochastic Models

If a simulation model does not contain any probabilistic (i.e., random) components, it is called deterministic; a complicated (and analytically intractable) system of differential equations describing a chemical reaction might be such a model. In deterministic models, the output is "determined" once the set of input quantities and relationships in the model have been specified; even though it might take a lot of computer time to evaluate what it is. Many systems, however, must be modeled as having at least some random input components; and these give rise to stochastic simulation models. Most queuing and inventory systems are modeled stochastically. Stochastic simulation models produce an output that is by itself random, and must therefore be treated as only an estimate of the true characteristics of the model. This is one of the main disadvantages of simulation.

2.4.7 Continuous vs. Discrete Models

Loosely speaking, we define discrete and continuous simulation models analogously to the way discrete and continuous systems were defined. It should be mentioned that a discrete model is not always used to model a discrete system and vice versa. The decision whether to use a discrete or a continuous model for a particular system depends on the specific objectives of the study. For example, a model of traffic flow on a freeway would be discrete if the characteristics and movement of individual cars are important. Alternatively, if the cars can be treated "in the aggregate," the flow of traffic can be described by differential equations in a continuous model. The continuous and discrete functions are shown in Figure 2.3.

x——x