Chapter 5
Types of Models

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5.1 Introduction

A model is an abstraction of some system. The system can be a man-made system (e.g., a manufactory plant or a health-care system) or a natural system (e.g., weather or biological). Models of systems are used for various purposes such as for developing system theories, understanding a system's behavior, predicting some system outcome, designing a new system, or modifying an existing system. We note that there may be different models of the same system as models can be developed for different purposes. Usually, a parsimonious model of a system is desired, meaning the model is as simple as possible yet meets its purpose. Also, the accuracy of a model required is only what is needed to satisfy its use or purpose. Models are commonly used in the study of a system instead of the system itself because often experiments cannot be performed on the system (e.g., if the system does not exist) or it is too costly to experiment on the system. There are four basic types of models: iconic, graphical, analog, and mathematical.

5.2 Iconic Models

Iconic models are physical models that "look like" the real system. An iconic model often has a different physical size than the real system; i.e., a different physical scale is used for the model than what the real system has. As children, we played with toy vehicles (e.g., trucks and trains) and dolls, which are iconic models. The globe is an iconic model of the world. Model aircrafts are tested in wind tunnels and model water vessels are tested in water tow tanks to improve their designs. Physical models of manufacturing systems, of buildings, and of portions of cities are used to aid in their design and to illustrate them. These models are iconic models.

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Mockups and prototypes are two other kinds of iconic models. They are often used in the design process of developing new products and systems. Mockups generally have a much lower fidelity than the real system (or product), commonly have the same physical size as the actual system, and usually are not operational. Different materials are often used in mockups such as plastic and cardboard. Mockups are an inexpensive way of obtaining feedback on a proposed product or system. Prototypes are generally the first sample of a system or product developed to further aid in the design process. They are usually at full scale, contain actual components, and may be operational.

An example of the use of a mockup and a prototype was for the development of a suite of new surgery rooms for a hospital in Syracuse, NY, USA. A mockup of the surgery room made of cardboard was used to obtain suggestions from the surgeons and nurses on the design of new surgery rooms. Then, a prototype of a new surgery room containing the actual components, but not operational, was used by the surgeons and nurses to evaluate and offer additional suggestions on the design of the surgery room. Better-designed surgery rooms were obtained as a result of using a mockup and a prototype. Also, some items that needed to be changed in a surgery room were found in the prototype that avoided those changes being made after the suite of surgery rooms were completed and thus those changed costs were circumvented.

5.3 Graphical Models

Graphical models are usually graphs (as the word graph is used in the theory of graphs; and also called networks) that use graphical symbols for nodes of which there may be different types and use edges (arcs) of which there may be different types to connect the nodes. See Fig. 5.1 for an example of a simple graph. Graphs

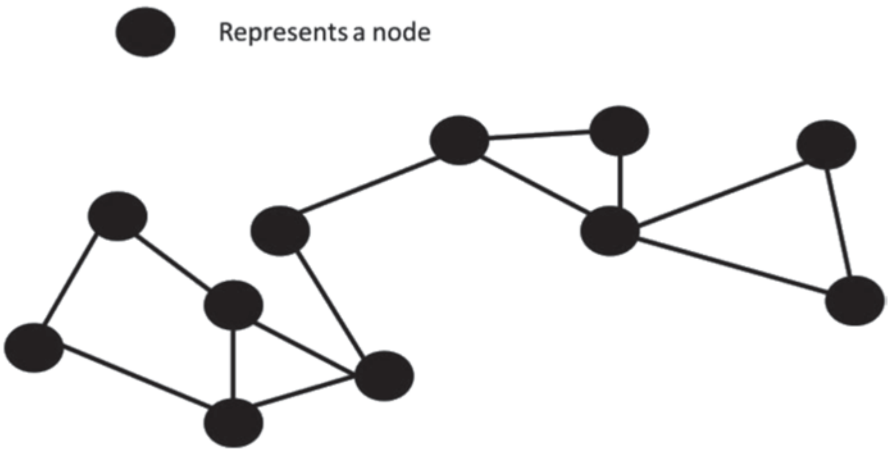

Fig. 5.1 A simple graph

are often directed graphs, which mean the edges have a direction. There are a variety of types of graphical systems for developing graphical models of systems. Graphical models have been used for a long period of time and they were originally developed manually. Today, there are interactive digital computer programs that can be used to develop a variety of types of graphical models. Graphical models are commonly used to specify simulation models for both analog and digital computer simulations. Systems for specification of graphical models for discrete-event digital simulation can often generate executable computer programs for simulation directly from graphical models. Graphical models of social networks are a new and growing area of the use of graphical models. There are a variety of analysis methods to analyze social network models. Graphical models usually are a great aid in communicating about a model of a system.

5.4 Analog Models

Analog models use a different set of characteristics to represent the characteristics of a system of interest. Prior to the invention and popularity of the digital computer, analog computers were commonly used to simulate (analyze) continuous systems of, e.g., physiological and ecological systems. Analog computers use numerical data represented by measurable physical variables, such as electrical voltage. An analog model of a system of interest is developed for the analog computer often specified by a graphical model and then that analog model is run on the analog computer to simulate the behavior of the system. Today, models of continuous systems are commonly investigated on digital computers using mathematical models instead of analog models on analog computers.

A different kind of analog model is the use of different physical materials of specific shapes in test chambers to represent some part of the environment. For example, such analog models, which are physical models, are used in test chambers for radar systems.

5.5 Mathematical Models

Mathematical models use mathematical language, which consists of mathematical symbols, expressions, relationships, operations, and logic, to describe a system. Often, mathematical models consist of a set of mathematical equations of which there are a variety of types; e.g., there are linear equations, nonlinear equations, differential equations, difference equations, and probabilistic equations. Mathematical models may be linear, nonlinear, probabilistic, continuous, discrete, or some combination of these, depending on the mathematics used. Mathematical models are commonly used in engineering.

There are three basic classes of mathematical models: empirical, optimization, and structural. Empirical models are developed from system data. Examples of empirical models are regression models, neural network models, and forecasting models. Empirical models are developed from relationships that are found in the data; system theories such as causal and logical relationships of a system are not used in their development. Thus, a weakness of empirical models is that if the data used to develop a model do not contain important relationships or if important relationships are not found in the data, the resulting model may have critical deficiencies. The use of empirical models is increasing because of the availability of large amounts of data that are being collected on systems and also with the use of data mining. We note that empirical models are numerical models.

Optimization models are developed from knowledge of a system. First, the decision variables are determined. Then, an objective function consisting of decision variables is defined that is to be minimized or maximized. Lastly, a set of constraints of the decision variables is developed. The solution to optimization models can be either analytical or numerical. The solution methods for most optimization models are numerical algorithms. An example of an optimization model is linear programming models, which have various numerical algorithms as solution methods. We note that optimization models are analytic models that have either an analytic or numerical solution method.

Structural models are descriptive models of a system developed using known causal and logical relationships that occur in the system. There are two fundamental types of structural models: analytic models and discrete-event simulation models. Analytic models use analytic equations and relationships to describe the causal relationships that occur in the system and these models are solved either analytically or numerically. One kind of analytic model is continuous simulation models that consist of differential equations, which are solved numerically on a digital computer. Another example is system dynamics as their models are analytic and the solution method is numerical. The solution methods for analytic models are often numerical algorithms.

Discrete-event simulation models "mimic" the behavior of the operation of a system by using causal and logical relationships that occur in the system of interest. A simulation model is "run" over model time to obtain a data realization of the behavior of the model, which is analyzed statistically to obtain an estimate of the result desired. Thus, discrete-event simulation is a numerical method. There are numerous discrete-event simulation languages to aid in performing discrete-event simulations. Discrete-event simulation models are commonly used to study complex systems since formulating analytic models or determining solutions to analytic models of complex systems are usually infeasible. For example, simple queueing (waiting line) systems are solved using analytic models and complex queueing systems are studied using discrete-event simulation models.

5.6 Model Selection

A common question asked is "What model or combination of models should be used to solve a specific problem?" There is no "rule of thumb" of which model or models to use. The selection of a model depends on the problem and also on the resources available. Resources include the expertise of the available engineers, the available computers, the available software, and possibly the available test facilities. Engineers work on a wide variety of types of problems and in many different application domains. It is the job of the engineer and modeler to decide the best solution approach and the type of model or models to use to solve a specific problem.

The use of graphical models is growing. One reason is graphical models are extremely useful in communicating about the model. A second reason is graphical models are increasingly being used to specify a model that is to be solved on a computer. A third reason is the availability of more computer software for graphical modeling.

Currently, there is a significant increase occurring in the use of mathematical models. One reason is the rapid growth in the use of empirical models because of the enormous amount of data being collected on systems that are being data-mined to obtain empirical models. A second reason is the increase in the capabilities of software that is becoming available for developing and solving structural models on the digital computer. As systems being designed and studied become ever more complex and larger, the use of structural models on the computer will continue to grow.