# 1

# SIMULATION MODELING

**LEARNING OBJECTIVES**

- To be able to describe what computer simulation is.
- To be able to discuss why simulation is an important analysis tool.
- To be able to list and describe the various types of computer simulations.
- To be able to describe a simulation methodology.

## 1.1 SIMULATION MODELING

In this book, you will learn how to model systems within a computer environment in order to analyze system design configurations. The models that you will build and exercise are called simulation models. When developing a simulation model, the modeler attempts to represent the system in such a way that the representation assumes or mimics the pertinent outward qualities of the system. This representation is called a simulation model. When you execute the simulation model, you are performing a simulation. In other words, simulation is an instantiation of the act of simulating. A simulation is often the next best thing to observing the real system. If you have confidence in your simulation, you can use it to infer how the real system will operate. You can then use your inference to understand and improve the system's performance.

In general, simulations can take on many forms. Almost everyone is familiar with the board game Life™. In this game, the players imitate life by going to college, getting a job, getting married, etc. and finally retiring. This board game is a simulation of life. As another

*Simulation Modeling and Arena®*, Second Edition. Manuel D. Rossetti.

example, the military performs war game exercises which are simulations of battlefield conditions. Both of these simulations involve a physical representation of the thing being simulated. The board game, the rules, and the players represent the simulation model. The battlefield, the rules of engagement, and the combatants are also physical representations. No wishful thinking will make the simulations that you develop in this book real. This is the first rule to remember about simulation. A simulation is only a model (representation) of the real thing. You can make your simulations as realistic as time and technology allows, but they are not the real thing. As you would never confuse a toy airplane with a real airplane, you should never confuse a simulation of a system with the real system. You may laugh at this analogy, but as you apply simulation to the real world, you will see analysts who forget this rule. Don't be one.

All the previous examples involved a physical representation or model (real things simulating other real things). In this book, you will develop computer models that simulate real systems. Ravindran et al. [1987] defined computer simulation as "A numerical technique for conducting experiments on a digital computer which involves logical and mathematical relationships that interact to describe the behavior of a system over time." Computer simulations provide an extra layer of abstraction from reality that allows fuller control of the progression of and the interaction with the simulation. In addition, even though computer simulations are one step removed from reality, they are often capable of providing constructs which cannot be incorporated into physical simulations. For example, an airplane flight simulator can have emergency conditions for which it would be too dangerous or costly to provide in a physical-based simulation training scenario. This representational power of computer modeling is one of the main reasons why computer simulation is used.

## 1.2 WHY SIMULATE?

Imagine trying to analyze the following situation. Patients arrive at an emergency room. The arrival of the patients to the emergency department occurs randomly and may vary with the day of the week and even the hour of the day. The hospital has a triage station, where the arriving patient's condition is monitored. If the patient's condition warrants immediate attention, the patient is expedited to an emergency room bed to be attended by a doctor and a nurse. In this case, the patient's admitting information may be obtained from a relative. If the patient does not require immediate attention, the patient goes through the admitting process, where the patient's information is obtained. The patient is then directed to the waiting room, to wait for allocation to a room, a doctor, and a nurse. The doctors and nurses within the emergency department must monitor the health of the patients by performing tests and diagnosing the patient's symptoms. This occurs on a periodic basis. As the patient receives care, the patient may be moved to and require other facilities [magnetic resonance imaging (MRI), X-ray, etc.]. Eventually, the patient is either discharged after receiving care or admitted to the main hospital. The hospital is interested in conducting a study of the emergency department in order to improve the care of the patients while better utilizing the available resources. To investigate this situation, you might need to understand the behavior of certain measures of performance:

- The average number of patients who are waiting.
- The average waiting time of the patients and their average total time in the emergency department.

- The average number of rooms required per hour.
- The average utilization of the doctors and nurses (and other equipment).

Because of the importance of emergency department operations, the hospital has historical records available on the operation of the department through its patient tracking system. With these records, you might be able to estimate the current performance of the emergency department. Despite the availability of this information, when conducting a study of the emergency department, you might want to propose changes to how the department will operate (e.g., staffing levels) in the future. Thus, you are faced with trying to predict the future behavior of the system and its performance when making changes to the system. In this situation, you cannot realistically experiment with the actual system without possibly endangering the lives or care of the patients. Thus, it would be better to model the system and test the effect of changes on the model. If the model has acceptable fidelity, then you can infer how the changes will affect the real system. This is where simulation techniques can be utilized.

If you are familiar with operations research and industrial engineering techniques, you may be thinking that the emergency department can be analyzed by using queuing models. Later chapters of this book will present more about queuing models; however, for the present situation, the application of queuing models will most likely be inadequate due to the complex policies for allocating nurses, doctors, and beds to the patients. In addition, the dynamic nature of this system (the non-stationary arrivals, changing staffing levels, etc.) cannot be well modeled with current analytical queuing models. Queuing models might be used to analyze portions of the system, but a total analysis of the dynamic behavior of the entire system is beyond the capability of these types of models. But, a total analysis of the system is not beyond simulation modeling.

A key advantage of simulation modeling is that it has the capability of modeling the entire system and its complex interrelationships. The representational power of simulation provides the flexible modeling that is required for capturing complex processes. As a result, all the important interactions among the different components of the system can be accounted for within the model. The modeling of these interactions is inherent in simulation modeling because simulation imitates the behavior of the real system (as closely as necessary). The prediction of the future behavior of the system is then achieved by monitoring the behavior of different modeling scenarios as a function of simulated time. Real-world systems are often too complex for analytical models and often too expensive to experiment with directly. Simulation models allow the modeling of this complexity and enable low cost experimentation to make inferences about how the actual system might behave.

## 1.3 TYPES OF COMPUTER SIMULATION

The main purpose of a simulation model is to allow observations about a particular system to be collected as a function of time. So far the word *system* has been used in much of the discussion, without formally discussing what a system is. According to Blanchard and Fabrycky [1990], a system is a set of interrelated components working together toward a common objective. The standard for systems engineering provides a deeper definition:

"A system is a composite of people, products, and processes that provide a capability to satisfy stated needs. A complete system includes the facilities, equipment (hardware and software), materials, services, data, skilled personnel, and techniques required to achieve, provide, and sustain system effectiveness." Air Force Systems Command (1991)

Figure 1.1 illustrates the fact that a system is embedded within an environment and that typically a system requires inputs and produces output using internal components. How you model a particular system will depend on the intended use of the model and how you perceive the system. The modeler's view of the system colors how they conceptualize it. For example, for the emergency room situation, "What are the system boundaries? Should the ambulance dispatching and delivery process be modeled? Should the details of the operating room be modeled?" Clearly, the emergency room has these components, but your conceptualization of it as a system may or may not include these items, and thus, your decisions regarding how to conceptualize the system will drive the level of abstraction within your modeling. An important point to remember is that two perfectly logical and rational people can look at the same thing and conceptualize that thing as two entirely different systems based on their "Weltanschauung" or world view.

Because how you conceptualize a system drives your modeling, it is useful to discuss some general system classifications. Systems might be classified by whether or not they are man-made (e.g., manufacturing system) or whether they are natural (e.g., solar system). A system can be physical (e.g., an airport) or conceptual (e.g., a system of equations). If stochastic or random behavior is an important component of the system, then the system is said to be stochastic; if not, then it is considered deterministic. One of the more useful ways to look at a system is whether it changes with respect to time. If a system does not change significantly with respect to time, it is said to be static, else it is called dynamic. If a system is dynamic, you might want to consider how it evolves with respect to time. A dynamic system is said to be discrete if the state of the system changes at discrete points in time. A dynamic system is said to be continuous if the state of the system changes continuously with time. This dichotomy is purely a function of your level of abstraction. If conceptualizing

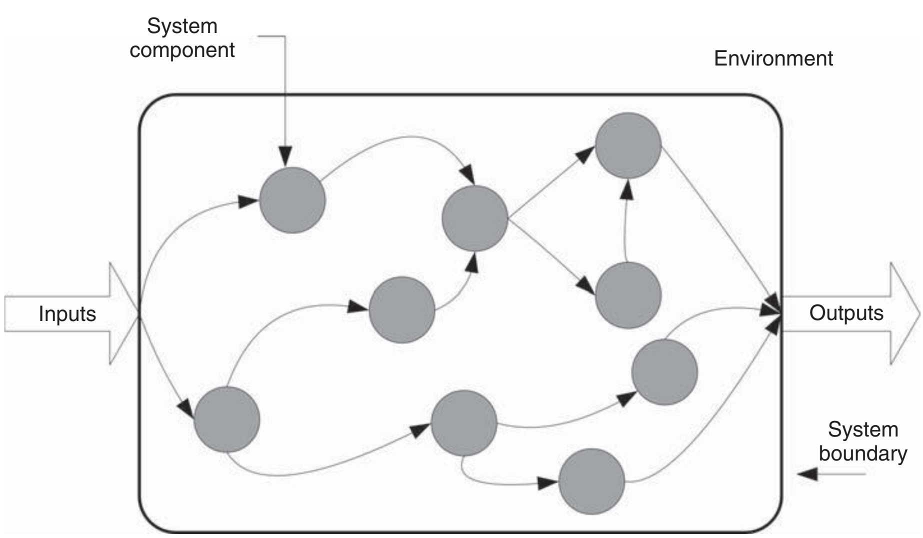


**Figure 1.1** A conceptualization of a system.

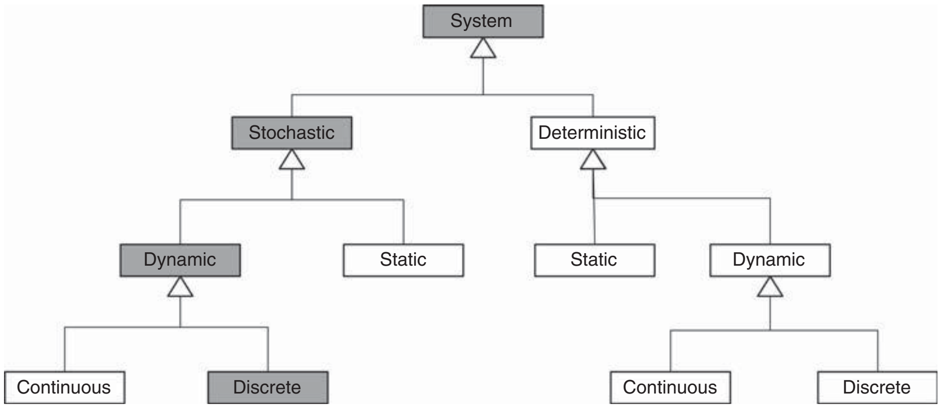


**Figure 1.2** General types of systems.

a system as discrete, serves our purposes, then you can call the system discrete. Figure 1.2 illustrates this classification of systems. This book primarily examines stochastic, dynamic, discrete systems.

The main purpose of a simulation model is to allow observations about a particular system to be gathered as a function of time. From that standpoint, there are two distinct types of simulation models: (i) discrete event and (ii) continuous.

Just as discrete systems change at discrete points in time, in a discrete-event simulation, observations are gathered at selected points in time when certain changes take place in the system. These selected points in time are called events. On the other hand, continuous simulation requires that observations be collected continuously at every point in time (or at least that the system is described for all points in time). The types of models to be examined in this book are called discrete-event simulation models.

To illustrate the difference between the two types of simulation models, contrast a fast food service counter with that of oil loading facility that is filling tankers. In the fast food service counter system, changes in the status of the system occur either when a customer arrives to place an order or when the customer receives their food. At these two events, measures such as queue length and waiting time will be affected. At all the other points in time, these measures remain either unchanged (e.g., queue length) or not yet ready for observation (e.g., waiting time of the customer). For this reason, the system does not need to be observed on a continuous basis. The system need only be observed at selected discrete points in time, resulting in the applicability of a discrete-event simulation model.

In the case of the oil tanker loading example, one of the measures of performance is the amount of oil in each tanker. Because the oil is a liquid, it cannot be readily divided into discrete components. That is, it flows continuously into the tanker. It is not necessary (or practical) to track each molecule of oil individually when you only care about the level of the oil in the tanker. In this case, a model of the system must describe the rate of flow over time and the output of the model is presented as a function of time. Systems such as these are often modeled using differential equations. The solution of these equations involves numerical methods that integrate the state of the modeled system over time. This, in essence, involves dividing time into small equal intervals and stepping through time.

Often both the discrete and continuous viewpoints are relevant in modeling a system. For example, if oil tanker arrives at the port to be filled, we have an arrival event that changes