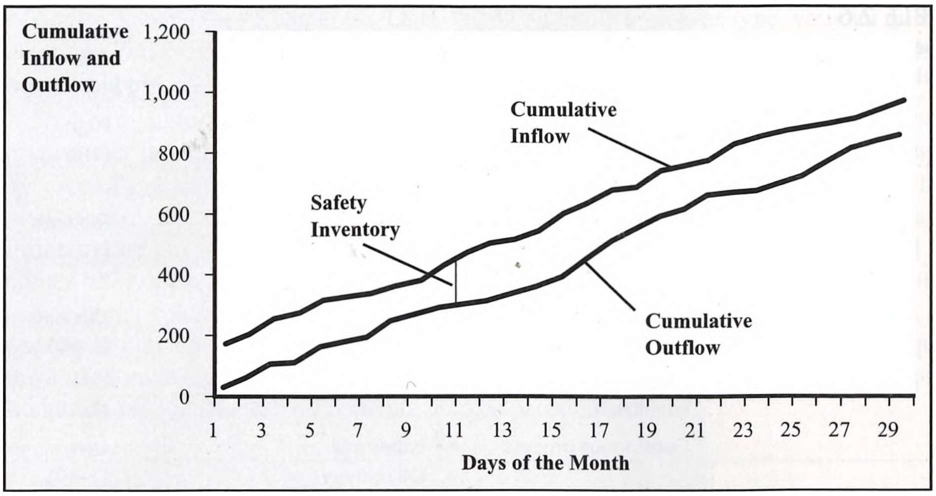
FIGURE 2.12
Safety Inventory at a Blood Bank



The resulting inventory thereby can be seen as a way to hedge against the underlying demand uncertainty. It might reflect a one-shot decision, for example, in the case of a book retailer selling short-life-cycle products such as newspapers or magazines. If we consider a title with a longer product life cycle (e.g., children's books), the book retailer will be able to replenish books more or less continuously over time.

Figure 2.12 shows the example of the blood bank in the Presbyterian Hospital in Philadelphia. While the detailed inflow and consumption of blood units vary over the course of the month, the hospital always has a couple of days of blood in inventory. Given that blood perishes quickly, the hospital wants to keep only a small inventory at its facility, which it replenishes from the regional blood bank operated by the Red Cross.

2.6 The Product–Process Matrix

Processes leading to the supply of goods or services can take many different forms. Some processes are highly automated, while others are largely manual. Some processes resemble the legendary Ford assembly line, while others resemble more the workshop in your local bike store. Empirical research in operations management, which has looked at thousands of processes, has identified five "clusters" or types of processes. Within each of the five clusters, processes are very similar concerning variables such as the number of different product variants they offer or the production volume they provide. Table 2.6 describes these different types of processes.

By looking at the evolution of a number of industries, Hayes and Wheelwright (1979) observed an interesting pattern, which they referred to as the product–process matrix (see Figure 2.13). The product–process matrix stipulates that over its life cycle, a product typically is initially produced in a job shop process. As the production volume of the product increases, the production process for the product moves from the upper left of the matrix to the lower right.

For example, the first automobiles were produced using job shops, typically creating one product at a time. Most automobiles were unique; not only did they have different colors or add-ons, but they differed in size, geometry of the body, and many other aspects. Henry Ford's introduction of the assembly line corresponded to a major shift along the diagonal of the product–process matrix. Rather than producing a couple of products in a job shop, Ford produced thousands of vehicles on an assembly line.

TABLE 2.6
Process Types and Their Characteristics

	Examples	Number of Different Product Variants	Product Volume (Units/Year)
Job shop	• Design company • Commercial printer • Formula 1 race car	High (100+)	Low (1–100)
Batch process	• Apparel sewing • Bakery • Semiconductor wafers	Medium (10–100)	Medium (100–100k)
Worker-paced line flow	• Auto assembly • Computer assembly	Medium (1–50)	High (10k–1M)
Machine-paced line flow	• Large auto assembly	Low (1–10)	High (10k–1M)
Continuous process	• Paper mill • Oil refinery • Food processing	Low (1–10)	Very high

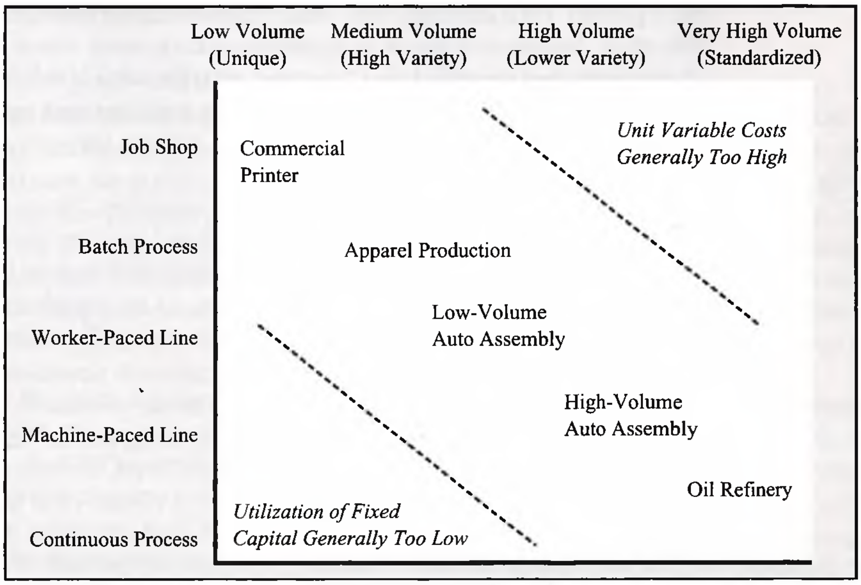
Note that the "off-diagonals" in the product–process matrix (the lower left and the upper right) are empty. This reflects that it is neither economical to produce very high volumes in a job shop (imagine if all of the millions of new vehicles sold in the United States every year were handcrafted in the same manner as Gottlieb Daimler created the first automobile) nor does it make sense to use an assembly line in order to produce only a handful of products a year.

We have to admit that few companies—if any—would be foolish enough to produce a high-volume product in a job shop. However, identifying a process type and looking at the product–process matrix is more than an academic exercise in industrial history. The usefulness of the product–process matrix lies in two different points:

1. Similar process types tend to have similar problems. For example, as we will discuss in Chapter 4, assembly lines tend to have the problem of line balancing (some workers working harder than others). Batch-flow processes tend to be slow in responding to

FIGURE 2.13
Product–Process Matrix

Source: Hayes and Wheelwright (1979).



customer demand (see Chapter 6). Thus, once you know a process type, you can quickly determine what type of problems the process is likely to face and what solution methods are most appropriate.

2. The "natural drift" of industries toward the lower right of Figure 2.13 enables you to predict how processes are likely to evolve in a particular industry. Consider, for example, the case of eye surgery. Up until the 1980s, corrective eye surgery was done in large hospitals. There, doctors would perform a large variety of very different eye-related cases. Fifteen years later, this situation had changed dramatically. Many highly specialized eye clinics have opened, most of them focusing on a limited set of procedures. These clinics achieve high volume and, because of the high volume and the lower variety of cases, can operate at much higher levels of efficiency. Similarly, semiconductor production equipment used to be assembled on a one-by-one basis, while now companies such as Applied Materials and Kulicke & Soffa operate worker-paced lines.

2.7 Summary

In this chapter, we emphasized the importance of looking at the operations of a firm not just in terms of the products that the firm supplies, but also at the processes that generate the supply. Looking at processes is especially important with respect to demand–supply mismatches. From the perspective of the product, such mismatches take the form of waiting times; from the perspective of the process, they take the form of inventory.

For any process, we can define three fundamental performance measures: inventory, flow time, and flow rate. The three measures are related by Little's Law, which states that the average inventory is equal to the average flow time multiplied by the average flow rate.

Little's Law can be used to find any of the three performance measures, as long as the other two measures are known. This is specifically important with respect to flow time, which is in practice frequently difficult to observe directly.

A measure related to flow time is inventory turns. Inventory turns, measured by 1/(flow time), captures how fast the flow units are transformed from input to output. It is an important benchmark in many industries, especially retailing. Inventory turns are also the basis of computing the inventory costs associated with one unit of supply.

2.8 Further Readings

De Groote (1994) is a very elegant note describing the basic roles of inventory. This note, as well as many other notes and articles by de Groote, takes a very "lean" perspective to operations management, resembling much more the tradition of economics as opposed to engineering.

Gaur, Fisher, and Raman (2002) provide an extensive study of retailing performance. They present various operational measures, including inventory turns, and show how they relate to financial performance measures.

The Hayes and Wheelwright (1979) reference is widely recognized as a pioneering article linking operations aspects to business strategy. Subsequent work by Hayes, Wheelwright, and Clark (1988) established operations as a key source for a firm's competitive advantage.

2.9 Practice Problems

Q 2.1* **(Dell)** What percentage of cost of a Dell computer reflects inventory costs? Assume Dell's yearly inventory cost is 40 percent to account for the cost of capital for financing the inventory, the warehouse space, and the cost of obsolescence. In other words, Dell incurs a cost of $40 for a $100 component that is in the company's inventory for one entire year. In 2001, Dell's 10-k reports showed that the company had $400 million in inventory and COGS of $26,442 million.

Q 2.2 **(Airline)** Consider the baggage check-in of a small airline. Check-in data indicate that from 9 a.m. to 10 a.m., 255 passengers checked in. Moreover, based on counting the number of

(* indicates that the solution is at the end of the book)