Guido Cozzi/Atlantide/Phototravel/Corbis

Characters perform at Cinderella's Castle in Magic Kingdom, Orlando, Florida, USA.

1

USING OPERATIONS TO CREATE VALUE

Disney

Disney Corporation is an internationally diversified entertainment and media enterprise comprising of five business segments of media networks (e.g., ABC, ESPN networks), parks and resorts (e.g., Disneyland and Disneyworld), studio entertainment (e.g., Pixar and Marvel studios), consumer products (e.g., toys, apparel, and books), and interactive media (e.g., Disney.com). It is one of the 30 companies that has been a part of the Dow Jones Industrial Average since 1991. With annual revenues of $45 billion in 2013, Disney is particularly well known for its theme parks that had a 17 percent increase in operating income to $2.2 billion in the last fiscal year alone. Its largest park, Walt Disney World Resort opened in Orlando, Florida, in 1971 and includes the Magic Kingdom, Epcot Center, Disney Studios, and Animal Kingdom.

Disney constantly evaluates and improves its processes to enhance customer experience. One of its recent innovations is a $1 billion comprehensive reservation and ride-planning system that can allow guests to book rides months in advance through a website or a smartphone app. Dubbed as MyMagic+, it works through a radio-frequency identification (RFID) chip embedded inside electronic wristbands or bracelets that guests wear once they check into a Disney theme park. Called MagicBands, they link electronically to centralized databases and can be used as admission tickets, credit or debit cards, or hotel room keys. Just by tapping them against electronic sensors, these MagicBands also become a form of payment for food, entertainment, and merchandise. Data from these wristbands can help Disney determine when to add more staff to which rides, decide how many employees in costumes should roam around at which locations in the park, determine restaurant menus and which souvenirs should be stocked based on customer preferences, and even send e-mail or text message alerts to guests when space opens up in an expedited queue at that guest's favorite ride such as Space Mountain or Pirates of the Caribbean. Apart from facilitating crowd control and data collection, this wearable technology helps Disney seamlessly personalize each guest's experience and change how they play and spend at the oft-advertised "Most Magical Place on Earth."

Despite some privacy concerns surrounding the use of RFID chips that can track a guest's identity and location within the theme parks, the new MyMagic+ system has multiple advantages. First, when visitors have well-planned schedules and forward visibility on what they are going to do on a given day on an hourly basis, they are less likely to jump ship to other theme parks in the area such as the Sea World or the popular Wizarding World of Harry Potter by Universal Studios. Second, when the logistics of moving from one attraction to another are simplified, guests have additional opportunities to spend more time and money in Disney restaurants and shops. Finally, by using this new RFID-enabled technology, Disney can effectively increase its capacity when it is needed the most. For instance, this new system allowed Disney to handle 3,000 additional visitors to the Magic Kingdom in Orlando during the Christmas rush. With other costs more or less fixed, the incremental revenues from additional guests flow directly to the bottom line. Increased profitability through technological and operational innovations help Disney provide more value to its guests as well as maintain its leadership position in the entertainment industry on multiple dimensions. It is also one among many other reasons why despite the price of entrance tickets crossing an average of $100 per day inclusive of taxes, an increase of 45 percent since 2005, there is no end in sight to the large crowds flooding Disney's theme parks.

Sources: Christopher Palmeri, "Disney Bets $1 Billion on Technology to Track Theme Park Visitors," *Bloomberg Business Week* (March 7, 2014); Justin Bachman, "Disney's Magic Kingdom Nears $100 Tickets, and the Crowds Keep Coming," *Bloomberg Business Week* (February 25, 2014); **http://thewaltdisneycompany.com/about-disney/company-overview**; **http://en.wikipedia.org/wiki/Disney** (August 18, 2014).

LEARNING GOALS *After reading this chapter, you should be able to:*

1. Describe the role of operations in an organization and its historical evolution over time.
2. Describe the process view of operations in terms of inputs, processes, outputs, information flows, suppliers, and customers.
3. Describe the supply chain view of operations in terms of linkages between core and support processes.
4. Define an operations strategy and its linkage to corporate strategy and market analysis.
5. Identify nine competitive priorities used in operations strategy, and explain how a consistent pattern of decisions can develop organizational capabilities.
6. Identify the latest trends in operations management, and understand how given these trends, firms can address the challenges facing operations and supply chain managers in a firm.

Operations management refers to the systematic design, direction, and control of processes that transform inputs into services and products for internal, as well as external customers. As exemplified by Disney, it can be a source of competitive advantage for firms in both service as well as manufacturing sectors.

This book deals with managing those fundamental activities and processes that organizations use to produce goods and services that people use every day. A **process** is any activity or group of activities that takes one or more inputs, transforms them, and provides one or more outputs for its customers. For organizational purposes, processes tend to be clustered together into operations. An **operation** is a group of resources performing all or part of one or more processes. Processes can be linked together to form a **supply chain**, which is the interrelated series of processes within a firm and across different firms that produce a service or product to the satisfaction of customers.[1] A firm can have multiple supply chains, which vary by the product or service provided. **Supply chain management** is the synchronization of a firm's processes with those of its suppliers and customers to match the flow of materials, services, and information with customer demand. As we will learn throughout this book, all firms have processes and supply chains. Sound operational planning and design of these processes, along with internal and external coordination within its supply chain, can create wealth and value for a firm's diverse stakeholders.

operations management
The systematic design, direction, and control of processes that transform inputs into services and products for internal, as well as external, customers.

process
Any activity or group of activities that takes one or more inputs, transforms them, and provides one or more outputs for its customers.

operation
A group of resources performing all or part of one or more processes.

supply chain
An interrelated series of processes within and across firms that produces a service or product to the satisfaction of customers.

supply chain management
The synchronization of a firm's processes with those of its suppliers and customers to match the flow of materials, services, and information with customer demand.

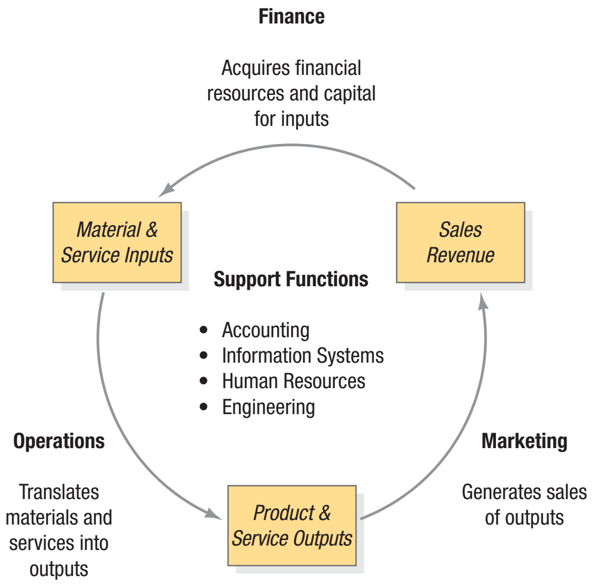
Role of Operations in an Organization

Broadly speaking, operations and supply chain management underlie all departments and functions in a business. Whether you aspire to manage a department or a particular process within it, or you just want to understand how the process you are a part of fits into the overall fabric of the business, you need to understand the principles of operations and supply chain management.

Operations serve as an excellent career path to upper management positions in many organizations. The reason is that operations managers are responsible for key decisions that affect the success of the organization. In manufacturing firms, the head of operations usually holds the title chief operations officer (COO) or vice president of manufacturing (or of production or operations). The corresponding title in a service organization might be COO or vice president (or director) of operations. Reporting to the head of operations are the managers of departments such as customer service, production and inventory control, and quality assurance.

Figure 1.1 shows operations as one of the key functions within an organization. The circular relationships in Figure 1.1 highlight the importance of the coordination among the three mainline functions of any business, namely, (1) operations, (2) marketing, and (3) finance. Each function is unique and has its own knowledge and skill areas, primary responsibilities, processes, and decision domains. From an external perspective, finance generates resources, capital, and funds from investors and sales of its goods and services in the marketplace. Based on business strategy, the finance and operations functions then decide how to invest these resources and convert them into physical assets and material inputs. Operations subsequently transforms these material and service inputs into product and service outputs. These outputs must match the characteristics that can be sold in the selected markets by marketing. Marketing is responsible for producing sales revenue of the outputs, which become returns to investors and capital for supporting operations. Functions such as accounting, information systems, human resources, and engineering make the firm complete by providing essential information, services, and other managerial support.

These relationships provide direction for the business as a whole and are aligned to the same strategic intent. It is important to understand the entire circle, and not just the individual functional areas. How well these functions work together determines the effectiveness of the organization. Functions should be integrated and should pursue a common strategy. Success depends on how well they are able to do so. No part of this circle can be dismissed or minimized without loss of effectiveness, and regardless of how departments and functions are individually managed; they are always linked together through processes. Thus, a firm competes not only by offering new services and products, creative marketing, and skillful finance but also through its unique competencies in operations and sound management of core processes.



▲ **FIGURE 1.1**
Integration between Different Functional Areas of a Business

[1]The terms *supply chain* and *value chain* are sometimes used interchangeably.

Historical Evolution and Perspectives

The history of modern operations and supply chain management is rich and over two hundred years old, even though its practice has been around in one form or another for centuries. James Watt invented the steam engine in 1785. The subsequent establishment of railroads facilitated efficient movement of goods throughout Europe, and eventually even in distant colonies such as India. With the invention of the cotton gin in 1794, Eli Whitney introduced the concept of interchangeable parts. It revolutionized the art of machine-based manufacturing, and coupled with the invention of the steam engine, lead to the great industrial revolution in England and the rest of Europe. The textile industry was one of the earliest industries to be mechanized. The industrial revolution gradually spread to the United States and the rest of the world in the nineteenth century and was accompanied by such great innovations as the internal combustion engine, steam-powered ships, metallurgy of iron making, large-scale production of chemicals, and invention of machine tools, among others. The foundations of modern manufacturing and technological breakthroughs were also inspired by the creation of a mechanical computer by Charles Babbage in the early part of the nineteenth century. He also pioneered the concept of division of labor, which laid the foundation for scientific management of operations and supply chain management that was further improved upon by Frederick Taylor in 1911.

Martyn Goddard/Corbis

The Ford Motor Company, founded in 1903, produced about one million Model T's in 1921 alone.

Three other landmark events from the twentieth century define the history of operations and supply chain management. First is the invention of the assembly line for the Model T car by Henry Ford in 1909. The era of mass production was born, where complex products like automobiles could be manufactured in large numbers at affordable prices through repetitive manufacturing. Second, Alfred Sloan in the 1930s introduced the idea of strategic planning for achieving product proliferation and variety, with the newly founded General Motors Corporation offering "a car for every purse and purpose." Finally, with the publication of the Toyota Production System book in Japanese in 1978, Taiichi Ohno laid the groundwork for removing wasteful activities from an organization, a concept that we explore further in this book while learning about lean systems.

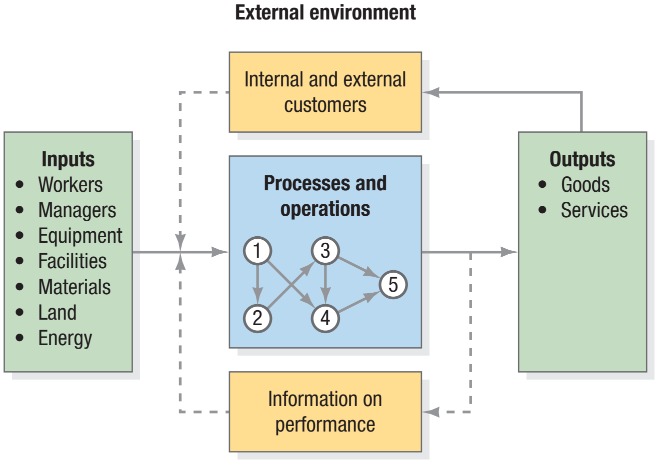
The recent history of operations and supply chains over the past three decades has been steeped in technological advances. The 1980s were characterized by wide availability of computer-aided design (CAD), computer-aided manufacturing (CAM), and automation. Information technology applications started playing an increasingly important role in the 1990s and started connecting the firm with its extended enterprise through Enterprise Resource Planning Systems and outsourced technology hosting for supply chain solutions. Service organizations like Federal Express, United Parcel Service (UPS), and Walmart also became sophisticated users of information technology in operations, logistics, and management of supply chains. The new millennium has seen an acceleration of this trend, along with an increased focus on sustainability and the natural environment. We cover all these ideas and topical areas in greater detail throughout this book.

A Process View

You might wonder why we begin by looking at processes rather than at departments or even the firm. The reason is that a process view of the firm provides a much more relevant picture of the way firms actually work. Departments typically have their own set of objectives, a set of resources with capabilities to achieve those objectives, and managers and employees responsible for performance. Some processes, such as billing, may be so specific that they are contained wholly within a single department, such as accounting.

The concept of a process, however, can be much broader. A process can have its own set of objectives, involve a work flow that cuts across departmental boundaries, and require resources from several departments. You will see examples throughout this text of companies that discovered how to use their processes to gain a competitive advantage. You will notice that the key to success in many organizations is a keen understanding of how their processes work, since an organization is only as effective as its processes. Therefore, operations management is relevant and important for all students, regardless of major, because all departments have processes that must be managed effectively to gain a competitive advantage.

How Processes Work



▲ **FIGURE 1.2**
Processes and Operations

Figure 1.2 shows how processes work in an organization. Any process has inputs and outputs. Inputs can include a combination of human resources (workers and managers), capital (equipment and facilities), purchased materials and services, land, and energy. The numbered circles in Figure 1.2 represent operations through which services, products, or customers pass and where processes are performed. The arrows represent flows and can cross because one job or customer can have different requirements (and thus a different flow pattern) than the next job or customer.

Processes provide outputs to customers. These outputs may often be services (that can take the form of information) or tangible products. Every process and every person in an organization has customers. Some are **external customers**, who may be end users or intermediaries (e.g., manufacturers, financial institutions, or retailers) buying the firm's finished services or products. Others are **internal customers**, who may be employees in the firm whose process inputs are actually the outputs of earlier processes managed within the firm. Either way, processes must be managed with the customer in mind.

In a similar fashion, every process and every person in an organization relies on suppliers. **External suppliers** may be other businesses or individuals who provide the resources, services, products, and materials for the firm's short-term and long-term needs. Processes also have **internal suppliers**, who may be employees or processes that supply important information or materials.

Inputs and outputs vary depending on the service or product provided. For example, inputs at a jewelry store include merchandise, the store building, registers, the jeweler, and customers; outputs to external customers are services and sold merchandise. Inputs to a factory manufacturing blue jeans include denim, machines, the plant, workers, managers, and services provided by outside consultants; outputs are clothing and supporting services. The fundamental role of inputs, processes, and customer outputs holds true for processes at all organizations.

Figure 1.2 can represent a whole firm, a department, a small group, or even a single individual. Each one has inputs and uses processes at various operations to provide outputs. The dashed lines represent two special types of input: participation by customers and information on performance from both internal and external sources. Participation by customers occurs not only when they receive outputs but also when they take an active part in the processes, such as when students participate in a class discussion. Information on performance includes internal reports on customer service or inventory levels and external information from market research, government reports, or telephone calls from suppliers. Managers need all types of information to manage processes most effectively.

external customers
A customer who is either an end user or an intermediary (e.g., manufacturers, financial institutions, or retailers) buying the firm's finished services or products.

internal customers
One or more employees or processes that rely on inputs from other employees or processes to perform their work.

external suppliers
The businesses or individuals who provide the resources, services, products, and materials for the firm's short-term and long-term needs.

internal suppliers
The employees or processes that supply important information or materials to a firm's processes.

nested process
The concept of a process within a process.

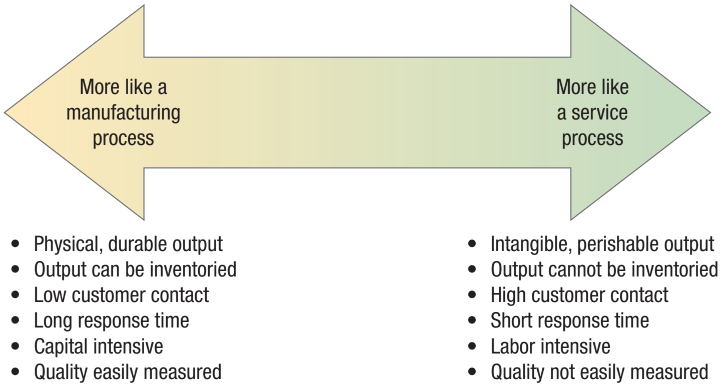
Nested Processes

Processes can be broken down into subprocesses, which in turn can be broken down further into still more subprocesses. We refer to this concept of a process within a process as a **nested process**. It may be helpful to separate one part of a process from another for several reasons. One person or one department may be unable to perform all parts of the process, or different parts of the process may require different skills. Some parts of the process may be designed for routine work while other parts may be geared for customized work. The concept of nested processes is illustrated in greater detail in Chapter 2, "Process Strategy and Analysis," where we reinforce the need to understand and improve activities within a business and each process's inputs and outputs.

Service and Manufacturing Processes

Two major types of processes are (1) service and (2) manufacturing. Service processes pervade the business world and have a prominent place in our discussion of operations management. Manufacturing processes are also important; without them the products we enjoy as part of our daily lives would not exist. In addition, manufacturing gives rise to service opportunities.

Differences Why do we distinguish between service and manufacturing processes? The answer lies at the heart of the design of competitive processes. While Figure 1.3 shows several distinctions between service and manufacturing processes along a continuum, the two key differences that we discuss in detail are (1) the nature of their output and (2) the degree of customer contact. In general, manufacturing processes also have longer response times, are more capital intensive, and their quality can be measured more easily than those of service processes.



▲ **FIGURE 1.3**
Continuum of Characteristics of Manufacturing and Service Processes

Manufacturing processes convert materials into goods that have a physical form we call products. For example, an assembly line produces a 370 Z sports car, and a tailor produces an outfit for the rack of an upscale clothing store. The transformation processes change the materials on one or more of the following dimensions:

1. Physical properties
2. Shape
3. Size (e.g., length, breadth, and height of a rectangular block of wood)
4. Surface finish
5. Joining parts and materials

The outputs from manufacturing processes can be produced, stored, and transported in anticipation of future demand.

If a process does not change the properties of materials on at least one of these five dimensions, it is considered a service (or nonmanufacturing) process. Service processes tend to produce intangible, perishable outputs. For example, the output from the auto loan process of a bank would be a car loan, and an output of the order fulfillment process of the U.S. Postal Service is the delivery of your letter. The outputs of service processes typically cannot be held in a finished goods inventory to insulate the process from erratic customer demands.

A second key difference between service processes and manufacturing processes is degree of customer contact. Service processes tend to have a higher degree of customer contact. Customers may take an active role in the process itself, as in the case of shopping in a supermarket, or they may be in close contact with the service provider to communicate specific needs, as in the case of a medical clinic. Manufacturing processes tend to have less customer contact. For example, washing machines are ultimately produced to meet retail forecasts. The process requires little information from the ultimate consumers (you and me), except indirectly through market surveys and market focus groups. Even though the distinction between service and manufacturing processes on the basis of customer contact is not perfect, the important point is that managers must recognize the degree of customer contact required when designing processes.

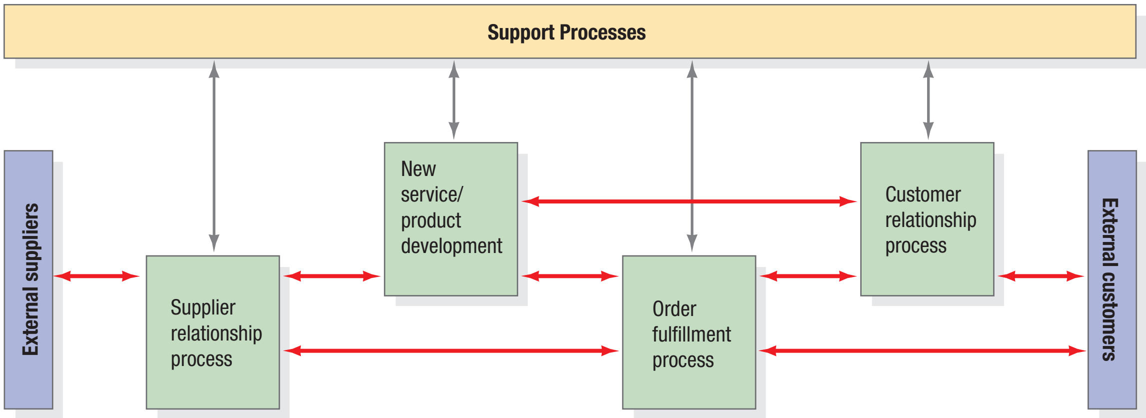
Similarities At the level of the firm, service providers do not just offer services and manufacturers do not just offer products. Patrons of a restaurant expect good service and good food. A customer purchasing a new computer expects a good product as well as a good warranty, maintenance, replacement, and financial services.

Further, even though service processes do not keep finished goods inventories, they do inventory their inputs. For example, hospitals keep inventories of medical supplies and materials needed for day-to-day operations. Some manufacturing processes, on the other hand, do not inventory their outputs because they are too costly. Such would be the case with low-volume customized products (e.g., tailored suits) or products with short shelf lives (e.g., daily newspapers).

When you look at what is being done at the process level, it is much easier to see whether the *process* is providing a service or manufacturing a product. However, this clarity is lost when the whole company is classified as either a manufacturer or a service provider because it often performs both types of processes. For example, the process of cooking a hamburger at a McDonald's is a manufacturing process because it changes the material's physical properties (dimension 1), as is the process of assembling the hamburger with the bun (dimension 5). However, most of the other processes visible or invisible to McDonald's customers are service processes. You can debate whether to call the whole McDonald's organization a service provider or a manufacturer, whereas classifications at the process level are much less ambiguous.

A Supply Chain View

Most services or products are produced through a series of interrelated business activities. Each activity in a process should add value to the preceding activities; waste and unnecessary cost should be eliminated. Our process view of a firm is helpful for understanding how services or products are produced and why cross-functional coordination is important, but it does not shed any light on the strategic benefits of the processes. The missing strategic insight is that processes must add value for customers throughout the supply chain. The concept of supply chains reinforces the link between processes and performance, which includes a firm's internal processes as well as those of its external customers and suppliers. It also focuses attention on the two main types of processes in the supply chain, namely (1) core processes and (2) support processes. Figure 1.4 shows the links between the core and support processes in a firm and a firm's external customers and suppliers within its supply chain.



▲ **FIGURE 1.4**
Supply Chain Linkages Showing Work and Information Flows

MyOMLab Animation

Core Processes

A **core process** is a set of activities that delivers value to external customers. Managers of these processes and their employees interact with external customers and build relationships with them, develop new services and products, interact with external suppliers, and produce the service or product for the external customer. Examples include a hotel's reservation handling, a new car design for an auto manufacturer, or Web-based purchasing for an online retailer like amazon.com. Of course, each of the core processes has nested processes within it.

In this text we focus on four core processes:

1. *Supplier Relationship Process.* Employees in the **supplier relationship process** select the suppliers of services, materials, and information and facilitate the timely and efficient flow of these items into the firm. Working effectively with suppliers can add significant value to the services or products of the firm. For example, negotiating fair prices, scheduling on-time deliveries, and gaining ideas and insights from critical suppliers are just a few of the ways to create value.
2. *New Service/Product Development Process.* Employees in the **new service/product development process** design and develop new services or products. The services or products may be developed to external customer specifications or conceived from inputs received from the market in general.
3. *Order Fulfillment Process.* The **order fulfillment process** includes the activities required to produce and deliver the service or product to the external customer.
4. *Customer Relationship Process,* sometimes referred to as *customer relationship management.* Employees involved in the **customer relationship process** identify, attract, and build relationships with external customers and facilitate the placement of orders by customers. Traditional functions, such as marketing and sales, may be a part of this process.

core process
A set of activities that delivers value to external customers.

supplier relationship process
A process that selects the suppliers of services, materials, and information and facilitates the timely and efficient flow of these items into the firm.

new service/product development process
A process that designs and develops new services or products from inputs received from external customer specifications or from the market in general through the customer relationship process.

order fulfillment process
A process that includes the activities required to produce and deliver the service or product to the external customer.

customer relationship process
A process that identifies, attracts, and builds relationships with external customers and facilitates the placement of orders by customers, sometimes referred to as *customer relationship management.*

Support Processes

A **support process** provides vital resources and inputs to the core processes and is essential to the management of the business. Processes as such are not just in operations but are found in accounting, finance, human resources, management information systems, and marketing. The human resources function in an organization provides many support processes such as recruiting and hiring workers who are needed at different levels of the organization, training the workers for skills and knowledge needed to properly execute their assigned responsibilities, and establishing incentive and compensation plans that reward employees for their performance. The legal department puts in place support processes that ensure that the firm is in compliance with the rules and regulations under which the business operates. The accounting function supports processes that track how the firm's financial resources are being created and allocated over time, while the information systems function is responsible for the movement and processing of data and information needed to make business decisions. Organizational structure throughout the many diverse industries varies, but for the most part, all organizations perform similar business processes. Table 1.1 lists a sample of them that are outside the operations area.

All of these support processes must be managed to create as much value for the firm and its customers and are therefore vital to the execution of core processes highlighted in Figure 1.4. Managers of these processes must understand that they cut across the organization, regardless of whether the firm is organized along functional, product, regional, or process lines.

support process
A process that provides vital resources and inputs to the core processes and therefore is essential to the management of the business.

TABLE 1.1 ILLUSTRATIVE BUSINESS PROCESSES OUTSIDE OF OPERATIONS

Activity-based costing	Employee benefits	Help desks
Asset management	Employee compensation	IT networks
Billing budget	Employee development	Payroll
Complaint handling	Employee recruiting	Records management
Credit management	Employee training	Research and development
Customer satisfaction	Engineering	Sales
Data warehousing	Environment	Security management
Data mining	External communications	Waste management
Disaster recovery	Finance	Warranty

Supply Chain Processes

supply chain processes

Business processes that have external customers or suppliers.

Supply chain processes are business processes that have external customers or suppliers. Table 1.2 illustrates some common supply chain processes.

TABLE 1.2 SUPPLY CHAIN PROCESS EXAMPLES

Process	Description	Process	Description
Outsourcing	Exploring available suppliers for the best options to perform processes in terms of price, quality, delivery time, environmental issues	**Customer Service**	Providing information to answer questions or resolve problems using automated information services as well as voice-to-voice contact with customers
Warehousing	Receiving shipments from suppliers, verifying quality, placing in inventory, and reporting receipt for inventory records	**Logistics**	Selecting transportation mode (train, ship, truck, airplane, or pipeline) scheduling both inbound and outbound shipments, and providing intermediate inventory storage
Sourcing	Selecting, certifying, and evaluating suppliers and managing supplier contracts	**Cross-docking**	Packing of products of incoming shipments so they can be easily sorted more economically at intermediate warehouses for outgoing shipments to their final destination

These supply chain processes should be documented and analyzed for improvement, examined for quality improvement and control, and assessed in terms of capacity and bottlenecks. Supply chain processes will be only as good as the processes within the organization that have only internal suppliers and customers. Each process in the chain, from suppliers to customers, must be designed and managed to add value to the work performed.

Operations Strategy

operations strategy

The means by which operations implements the firm's corporate strategy and helps to build a customer-driven firm.

Operations strategy specifies the means by which operations implements corporate strategy and helps to build a customer-driven firm. It links long-term and short-term operations decisions to corporate strategy and develops the capabilities the firm needs to be competitive. It is at the heart of managing processes and supply chains. A firm's internal processes are only building blocks: They need to be organized to ultimately be effective in a competitive environment. Operations strategy is the linchpin that brings these processes together to form supply chains that extend beyond the walls of the firm, encompassing suppliers as well as customers. Since customers constantly desire change, the firm's operations strategy must be driven by the needs of its customers.

Developing a customer-driven operations strategy is a process that begins with *corporate strategy*, which, as shown in Figure 1.5, coordinates the firm's overall goals with its core processes. It determines the markets the firm will serve and the responses the firm will make to changes in the environment. It provides the resources to develop the firm's core competencies and core processes, and it identifies the strategy the firm will employ in international markets. Based on corporate strategy, a *market analysis* categorizes the firm's customers, identifies their needs, and assesses competitors' strengths. This information is used to develop *competitive priorities*. These priorities help managers develop the services or products and the

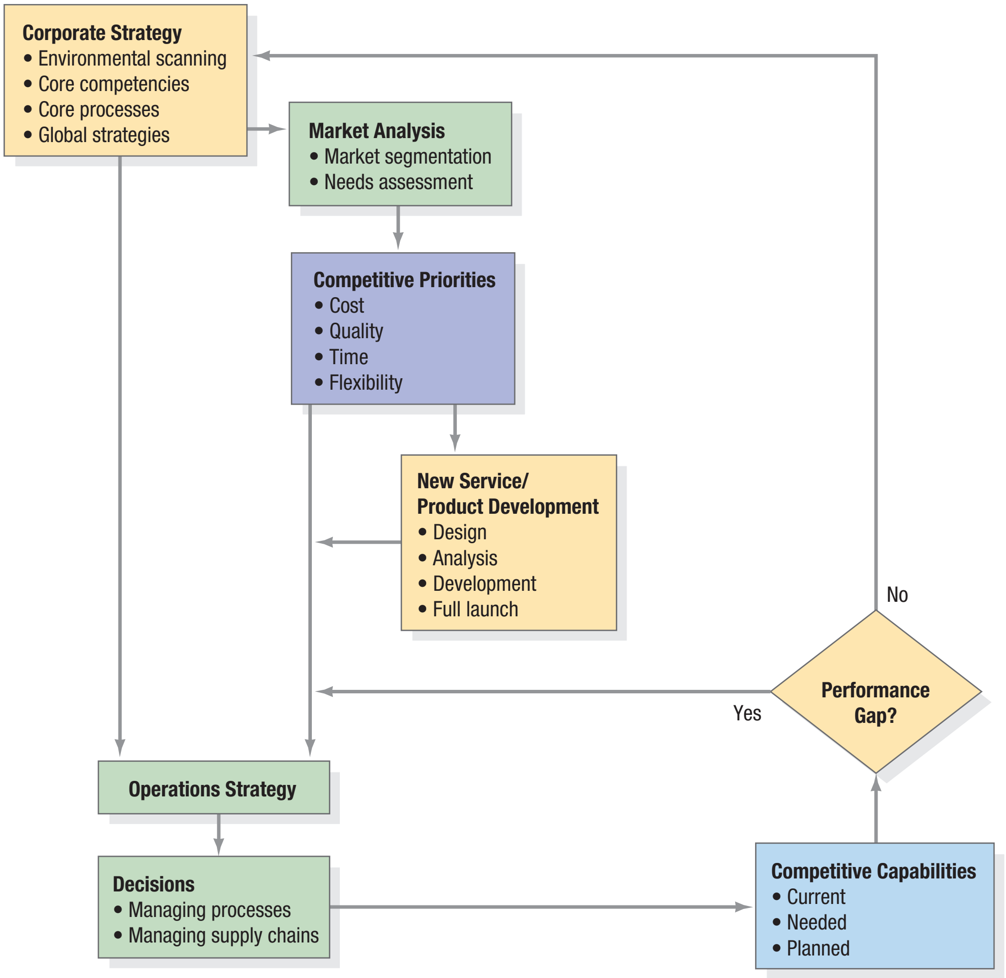


FIGURE 1.5
Connection Between Corporate Strategy and Key Operations Management Decisions

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processes needed to be competitive in the marketplace. Competitive priorities are important to the design of existing as well as new services or products, the processes that will deliver them, and the operations strategy that will develop the firm's capabilities to fulfill them. Developing a firm's operations strategy is a continuous process because the firm's capabilities to meet the competitive priorities must be periodically checked, and any gaps in performance must be addressed in the operations strategy.

Corporate Strategy

Corporate strategy provides an overall direction that serves as the framework for carrying out all the organization's functions. It specifies the business or businesses the company will pursue, isolates new opportunities and threats in the environment, and identifies growth objectives.

Developing a corporate strategy involves four considerations: (1) environmental scanning: monitoring and adjusting to changes in the business environment, (2) identifying and developing the firm's core competencies, (3) developing the firm's core processes, and (4) developing the firm's global strategies.

Environmental Scanning The external business environment in which a firm competes changes continually and an organization needs to adapt to those changes. Adaptation begins with *environmental scanning*, the process by which managers monitor trends in the environment (e.g., the industry, the marketplace, and society) for potential opportunities or threats. A crucial reason for environmental scanning is to stay ahead of the competition. Competitors may be gaining an edge by broadening service or product lines, improving quality, or lowering costs. New entrants into the market or competitors that offer substitutes for a firm's service or product may threaten continued profitability. Other important environmental concerns include economic trends, technological changes, political conditions, social changes (i.e., attitudes toward work), and the availability of vital resources. For example, car manufacturers recognize that dwindling oil reserves will eventually require alternative fuels for their cars. Consequently, they have designed prototype cars that use hydrogen or electric power as supplements to gasoline as a fuel.

Developing Core Competencies Good managerial skill alone cannot overcome environmental changes. Firms succeed by taking advantage of what they do particularly well—that is, the organization's unique strengths. **Core competencies** are the unique resources and strengths that an organization's management considers when formulating strategy. They reflect the collective learning of the organization, especially in how to coordinate processes and integrate technologies. These competencies include the following:

core competencies

The unique resources and strengths that an organization's management considers when formulating strategy.

1. *Workforce.* A well-trained and flexible workforce allows organizations to respond to market needs in a timely fashion. This competency is particularly important in service organizations, where customers come in direct contact with employees.
2. *Facilities.* Having well-located facilities (offices, stores, and plants) is a primary advantage because of the long **lead time** needed to build new ones. In addition, flexible facilities that can handle a variety of services or products at different levels of volume provide a competitive advantage.
3. *Market and Financial Know-How.* An organization that can easily attract capital from stock sales, market and distribute its services or products, or differentiate them from similar services or products on the market has a competitive edge.
4. *Systems and Technology.* Organizations with expertise in information systems have an edge in industries that are data intensive, such as banking. Particularly advantageous is expertise in Internet technologies and applications, such as business-to-consumer and business-to-business systems. Having the patents on a new technology is also a big advantage.

lead time

The elapsed time between the receipt of a customer order and filling it.

Developing Core Processes A firm's core competencies should drive its core processes: customer relationship, new service or product development, order fulfillment, and supplier relationship. Many companies have all four processes, while others focus on a subset of them to better match their core competencies, since they find it difficult to be good at all four processes and still be competitive. For instance, in the credit card business within the banking industry, some companies primarily specialize in finding customers and maintaining relationships with them. American Airlines's credit card program reaches out and achieves a special affinity to customers through its marketing database. On the other hand, specialized credit card companies, such as Capital One, focus on service innovation by creating new features and pricing programs. Finally, many companies are taking over the order fulfillment process by managing the processing of credit card transactions and call centers. The important point is that every firm must evaluate its core competencies and choose to focus on those processes that provide it the greatest competitive strength.

Peter Foley/Bloomberg/Getty Images

Capital One Financial Corp. is a U.S.-based bank holding company specializing in credit cards, home loans, auto loans, banking, and savings products.

Developing Global Strategies Identifying opportunities and threats today requires a global perspective. A global strategy may include buying foreign services or parts, combating threats from foreign competitors, or planning ways to enter markets beyond traditional national boundaries. Although warding off threats from global competitors is necessary, firms should also actively seek to penetrate foreign markets. Two effective global strategies are (1) strategic alliances and (2) locating abroad.

One way for a firm to open foreign markets is to create a *strategic alliance*. A strategic alliance is an agreement with another firm that may take one of three forms. One form of strategic alliance is the *collaborative effort*, which often arises when one firm has core competencies that another needs but is unwilling (or unable) to duplicate. Such arrangements commonly arise out of buyer–supplier relationships. Another form of strategic alliance is the *joint venture*, in which two firms agree to produce a service or product jointly. This approach is often used by firms to gain access to foreign markets. Finally, *technology licensing* is a form of strategic alliance in which one company licenses its service or production methods to another. Licenses may be used to gain access to foreign markets.

Another way to enter global markets is to locate operations in a foreign country. However, managers must recognize that what works well in their home country might not work well elsewhere. The economic and political environment or customers' needs may be significantly different. For example, the family-owned chain Jollibee Foods Corporation became the dominant fast-food chain in the Philippines by catering to a local preference for sweet and spicy flavors, which it incorporates into its fried chicken, spaghetti, and burgers. Jollibee's strength is its creative marketing programs and an understanding of local tastes; it claims that its burger is similar to the one a Filipino would cook at home. McDonald's responded by introducing its own Filipino-style spicy burger, but competition is stiff. This example shows that to be successful, corporate strategies must recognize customs, preferences, and economic conditions in other countries.

Locating abroad is a key decision in the design of supply chains because it affects the flow of materials, information, and employees in support of the firm's core processes. Chapter 12, "Designing Effective Supply Chains," and Chapter 13, "Supply Chains and Logistics," offer more in-depth discussion of these other implications.

Market Analysis

One key to successfully formulating a customer-driven operations strategy for both service and manufacturing firms is to understand what the customer wants and how to provide it. A *market analysis* first divides the firm's customers into market segments and then identifies the needs of each segment. In this section, we examine the process of market analysis, and we define and discuss the concepts of market segmentation and needs assessment.

Market Segmentation *Market segmentation* is the process of identifying groups of customers with enough in common to warrant the design and provision of services or products that the group wants and needs. To identify market segments, the analyst must determine the characteristics that clearly differentiate each segment. The company can then develop a sound marketing program and an effective operating strategy to support it. For instance, The Gap, Inc., a major provider of casual clothes, targets teenagers and young adults while the parents or guardians of infants to 12-year-olds are the primary targets for its GapKids stores. At one time, managers thought of customers as a homogeneous mass market but now realize that two customers may use the same product for different reasons. Identifying the key factors in each market segment is the starting point in devising a customer-driven operations strategy.

Needs Assessment The second step in market analysis is to make a *needs assessment*, which identifies the needs of each segment and assesses how well competitors are addressing those needs. Each market segment's needs can be related to the service or product and its supply chain. Market needs should include both the tangible and intangible attributes and features of products and services that a customer desires. Market needs may be grouped as follows:

- *Service or Product Needs.* Attributes of the service or product, such as price, quality, and degree of customization.
- *Delivery System Needs.* Attributes of the processes and the supporting systems, and resources needed to deliver the service or product, such as availability, convenience, courtesy, safety, accuracy, reliability, delivery speed, and delivery dependability.
- *Volume Needs.* Attributes of the demand for the service or product, such as high or low volume, degree of variability in volume, and degree of predictability in volume.
- *Other Needs.* Other attributes, such as reputation and number of years in business, after-sale technical support, ability to invest in international financial markets, and competent legal services.

Once it makes this assessment, the firm can incorporate the needs of customers into the design of the service or product and the supply chain that must deliver it. We further discuss these new service and product development-related issues in Chapter 14, "Integrating the Supply Chain."

Competitive Priorities and Capabilities

A customer-driven operations strategy requires a cross-functional effort by all areas of the firm to understand the needs of the firm's external customers and to specify the operating capabilities the firm requires to outperform its competitors. Such a strategy also addresses the needs of internal customers because the overall performance of the firm depends upon the performance of its core and supporting processes, which must be coordinated to provide the overall desirable outcome for the external customer.

Competitive priorities are the critical operational dimensions a process or supply chain must possess to satisfy internal or external customers, both now and in the future. Competitive priorities are planned for processes and the supply chain created from them. They must be present to maintain or build market share or to allow other internal processes to be successful. Not all competitive priorities are critical for a given process; management selects those that are most important. **Competitive capabilities** are the cost, quality, time, and flexibility dimensions that a process or supply chain actually

competitive priorities

The critical dimensions that a process or supply chain must possess to satisfy its internal or external customers, both now and in the future.

competitive capabilities

The cost, quality, time, and flexibility dimensions that a process or supply chain actually possesses and is able to deliver.

possesses and is able to deliver. When the capability falls short of the priority attached to it, management must find ways to close the gap or else revise the priority.

We focus on nine broad competitive priorities that fall into the four capability groups of cost, quality, time, and flexibility. Table 1.3 provides definitions and examples of these competitive priorities, as well as how firms achieve them at the process level.

TABLE 1.3 | DEFINITIONS, PROCESS CONSIDERATIONS, AND EXAMPLES OF COMPETITIVE PRIORITIES

Cost	Definition	Processes Considerations	Example
1. **Low-cost operations**	Delivering a service or a product at the lowest possible cost to the satisfaction of external or internal customers of the process or supply chain	To reduce costs, processes must be designed and operated to make them efficient using rigorous process analysis that addresses workforce, methods, scrap or rework, overhead, and other factors, such as investments in new automated facilities or technologies to lower the cost per unit of the service or product.	**Costco** achieves low costs by designing all processes for efficiency, stacking products on pallets in warehouse-type stores, and negotiating aggressively with their suppliers. Costco can provide low prices to its customers because they have designed operations for low cost.
Quality			
2. **Top quality**	Delivering an outstanding service or product	To deliver top quality, a service process may require a high level of customer contact, and high levels of helpfulness, courtesy, and availability of servers. It may require superior product features, close tolerances, and greater durability from a manufacturing process.	**Rolex** is known globally for creating precision timepieces.
3. **Consistent quality**	Producing services or products that meet design specifications on a consistent basis	Processes must be designed and monitored to reduce errors, prevent defects, and achieve similar outcomes over time, regardless of the "level" of quality.	**McDonald's** standardizes work methods, staff training processes, and procurement of raw materials to achieve the same consistent product and process quality from one store to the next.
Time			
4. **Delivery speed**	Quickly filling a customer's order	Design processes to reduce lead time (elapsed time between the receipt of a customer order and filling it) through keeping backup capacity cushions, storing inventory, and using premier transportation options.	**Netflix** engineered its customer relationship, order fulfillment and supplier relationship processes to create an integrated Web-based system that allows its customers to watch multiple episodes of a TV program or movies in rapid succession.
5. **On-time delivery**	Meeting delivery-time promises	Along with processes that reduce lead time, planning processes (forecasting, appointments, order promising, scheduling, and capacity planning) are used to increase percent of customer orders shipped when promised (95% is often a typical goal).	**United Parcel Services (UPS)** uses its expertise in logistics and warehousing processes to deliver a very large volume of shipments on-time across the globe.
6. **Development speed**	Quickly introducing a new service or a product	Processes aim to achieve cross-functional integration and involvement of critical external suppliers in the service or product development process.	**Zara** is known for its ability to bring fashionable clothing designs from the runway to market quickly.
Flexibility			
7. **Customization**	Satisfying the unique needs of each customer by changing service or product designs	Processes with a customization strategy typically have low volume, close customer contact, and an ability to reconfigure processes to meet diverse types of customer needs.	**Ritz Carlton** customizes services to individual guest preferences.
8. **Variety**	Handling a wide assortment of services or products efficiently	Processes supporting variety must be capable of larger volumes than processes supporting customization. Services or products are not necessarily unique to specific customers and may have repetitive demands.	**Amazon.com** uses information technology and streamlined customer relationship and order fulfillment processes to reliably deliver a vast variety of items to its customers.
9. **Volume flexibility**	Accelerating or decelerating the rate of production of services or products quickly to handle large fluctuations in demand	Processes must be designed for excess capacity and excess inventory to handle demand fluctuations that can vary in cycles from days to months. This priority could also be met with a strategy that adjusts capacity without accumulation of inventory or excess capacity.	The **United States Post Office (USPS)** can have severe demand peak fluctuations at large postal facilities where processes are flexibly designed for receiving, sorting, and dispatching mail to numerous branch locations.

At times, management may emphasize a cluster of competitive priorities together. For example, many companies focus on the competitive priorities of delivery speed and development speed for their processes, a strategy called **time-based competition**. To implement the strategy, managers carefully define the steps and time needed to deliver a service or produce a product and then critically analyze each step to determine whether they can save time without hurting quality.

To link to corporate strategy, management assigns selected competitive priorities to each process (and the supply chains created from them) that are consistent with the needs of external as well as internal customers. Competitive priorities may change over time. For example, consider a high-volume standardized product, such as color ink-jet desktop printers. In the early stages of the ramp-up period when the printers had just entered the mass market, the manufacturing processes required consistent quality, delivery speed, and volume flexibility. In the later stages of the ramp-up when demand was high, the competitive priorities became low-cost operations, consistent quality, and on-time delivery. Competitive priorities must change and evolve over time along with changing business conditions and customer preferences.

The lavish interior lobby decor of the Ritz Carlton resort in Palm Beach, Florida, USA

America/Alamy

Order Winners and Qualifiers

Competitive priorities focus on what operations can do to help a firm be more competitive and are in response to what the market wants. Another useful way to examine a firm's ability to be successful in the marketplace is to identify the order winners and order qualifiers. An **order winner** is a criterion that customers use to differentiate the services or products of one firm from those of another. Order winners can include price (which is supported by low-cost operations) and other dimensions of quality, time, and flexibility. However, order winners also include criteria not directly related to the firm's operations, such as after-sale support (Are maintenance service contracts available? Is there a return policy?); technical support (What help do I get if something goes wrong? How knowledgeable are the technicians?); and reputation (How long has this company been in business? Have other customers been satisfied with the service or product?). It may take good performance on a subset of the order-winner criteria, cutting across operational as well as nonoperational criteria, to make a sale.

Order winners are derived from the considerations customers use when deciding which firm to purchase a service or product from in a given market segment. Sometimes customers demand a certain level of demonstrated performance before even contemplating a service or product. Minimal level required from a set of criteria for a firm to do business in a particular market segment is called an **order qualifier**. Fulfilling the order qualifier will not ensure competitive success; it will only position the firm to compete in the market. From an operations perspective, understanding which competitive priorities are order qualifiers and which ones are order winners is important for the investments made in the design and management of processes and supply chains.

Figure 1.6 shows how order winners and qualifiers are related to achieving the competitive priorities of a firm. If a minimum threshold level is not met for an order-qualifying dimension (consistent quality, for example) by a firm, then it would get disqualified from even being considered further by its customers. For example, there is a level of quality consistency that is minimally tolerable by customers in the auto industry. When the subcompact car Yugo built by Zastava Corporation could not sustain the minimal level of quality, consistency, and reliability expected by customers, it had to exit the U.S. car market in 1991 despite offering very low prices (order winner) of under $4,000. However, once the

time-based competition

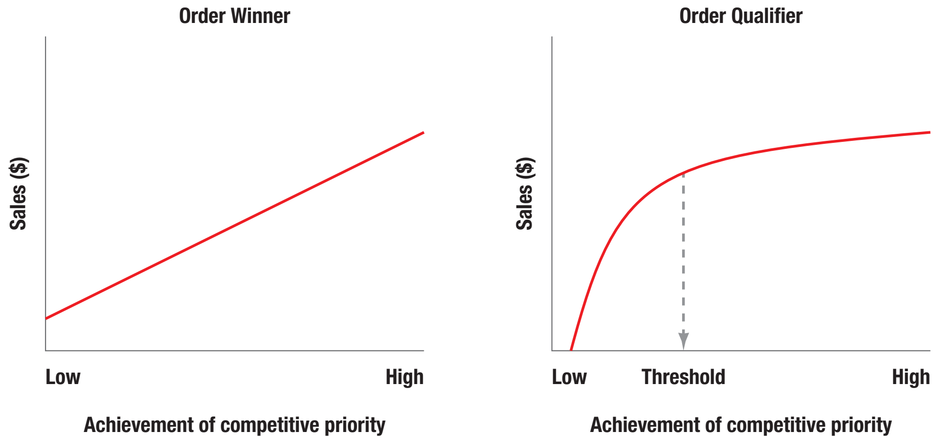
A strategy that focuses on the competitive priorities of delivery speed and development speed.

order winner

A criterion customers use to differentiate the services or products of one firm from those of another.

order qualifier

Minimal level required from a set of criteria for a firm to do business in a particular market segment.



▲ **FIGURE 1.6**
Relationship of Order Winners and Order Qualifiers to Competitive Priorities

MyOMLab Animation

firm qualifies by attaining consistent quality beyond the threshold, it may only gain additional sales at a very low rate by investing further in improving that order-qualifying dimension. In contrast, for an order-winning dimension (i.e., low price driven by low-cost operations), a firm can reasonably expect to gain appreciably greater sales and market share by continuously lowering its prices as long as the order qualifier (i.e., consistent quality) is being adequately met. Toyota Corolla and Honda Civic have successfully followed this route in the marketplace to become leaders in their target market segment.

Order winners and qualifiers are often used in competitive bidding. For example, before a buyer considers a bid, suppliers may be required to document their ability to provide consistent quality as measured by adherence to the design specifications for the service or component they are supplying (order qualifier). Once qualified, the supplier may eventually be selected by the buyer on the basis of low prices (order winner) and the reputation of the supplier (order winner).

Using Competitive Priorities: An Airline Example

To get a better understanding of how companies use competitive priorities, let us look at a major airline. We will consider two market segments: (1) first-class passengers and (2) coach passengers. Core services for both market segments are ticketing and seat selection, baggage handling, and transportation to the customer's destination. The peripheral services are quite different across the two market segments. First-class passengers require separate airport lounges; preferred treatment during check-in, boarding, and deplaning; more comfortable seats; better meals and beverages; more personal attention (cabin attendants who refer to customers by name); more frequent service from attendants; high levels of courtesy; and low volumes of passengers (adding to the feeling of being special). Coach passengers are satisfied with standardized services (no surprises), courteous flight attendants, and low prices. Both market segments expect the airline to hold to its schedule. Consequently, we can say that the competitive priorities for the first-class segment are *top quality* and *on-time delivery*, whereas the competitive priorities for the coach segment are *low-cost operations*, *consistent quality*, and *on-time delivery*.

The airline knows what its collective capabilities must be as a firm, but how does that get communicated to each of its core processes? Let us focus on the four core processes: (1) customer relationship, (2) new service or product development, (3) order fulfillment, and (4) supplier relationship. Competitive priorities are assigned to each core process to achieve the service required to provide complete customer satisfaction. Table 1.4 shows some possible assignments just to give you an idea of how this works.

Identifying Gaps between Competitive Priorities and Capabilities

Operations strategy translates service or product plans and competitive priorities for each market segment into decisions affecting the supply chains that support those market segments. Even if it is not formally stated, the current operations strategy for any firm is really the pattern of decisions that have been made for its processes and supply chains. As we have previously seen in Figure 1.5, corporate strategy provides the umbrella for key operations management decisions that contribute to the development of the firm's ability to compete successfully in the marketplace. Once managers determine the competitive priorities for a process, it is necessary to assess the *competitive capabilities* of the process. Any gap between a competitive priority and the capability to achieve that competitive priority must be closed by an effective operations strategy.

Developing capabilities and closing gaps is the thrust of operations strategy. To demonstrate how this works, suppose the management of a bank's credit card division decides to embark on a marketing campaign to significantly increase its business, while keeping costs low. A key process in this division is billing and payments. The division receives credit transactions from the merchants, pays the merchants, assembles and sends the bills to the credit card holders, and processes payments. The new marketing effort is expected to significantly increase the volume of bills and payments. In assessing the capabilities, the process must have to serve the bank's customers and to meet the

Andres Rodriguez/Fotolia

Flight attendants welcoming passengers aboard a commercial airline.

TABLE 1.4 COMPETITIVE PRIORITIES ACROSS DIFFERENT CORE PROCESSES FOR AN AIRLINE

	CORE PROCESSES			
Priority	**Supplier Relationship**	**New Service Development**	**Order Fulfillment**	**Customer Relationship**
Low Cost Operations	Costs of acquiring inputs must be kept to a minimum to allow for competitive pricing.		Airlines compete on price and must keep operating costs in check.	
Top Quality		New services must be carefully designed because the future of the airline industry depends on them.	High quality meal and beverage service delivered by experienced cabin attendants ensures that the service provided to first-class passengers is kept top notch.	High levels of customer contact and lounge service for the first-class passengers.
Consistent Quality	Quality of the inputs must adhere to the required specifications. In addition, information provided to suppliers must be accurate.		Once the quality level is set, it is important to achieve it every time.	The information and service must be error free.
Delivery Speed				Customers want immediate information regarding flight schedules and other ticketing information.
On time delivery	Inputs must be delivered to tight schedules.		The airline strives to arrive at destinations on schedule, otherwise passengers might miss connections to other flights.	
Development Speed		It is important to get to the market fast to preempt the competition.		
Customization		The process must be able to create unique services.		
Variety	Many different inputs must be acquired, including maintenance items, meals and beverages.		Maintenance operations are required for a variety of aircraft models.	The process must be capable of handling the service needs of all market segments and promotional programs.
Volume Flexibility	The process must be able to handle variations in supply quantities efficiently.			

challenges of the new market campaign; management assigns the following competitive priorities for the billing and payments process:

- *Low-Cost Operations.* It is important to maintain low costs in the processing of the bills because profit margins are tight.
- *Consistent Quality.* The process must consistently produce bills, make payments to the merchants, and record payments from the credit card holders accurately.
- *Delivery Speed.* Merchants want to be paid for the credit purchases quickly.
- *Volume Flexibility.* The marketing campaign is expected to generate many more transactions in a shorter period of time.

Management assumed that customers would avoid doing business with a bank that could not produce accurate bills or payments. Consequently, consistent quality is an order qualifier for this process.

TABLE 1.5 OPERATIONS STRATEGY ASSESSMENT OF THE BILLING AND PAYMENT PROCESS

Competitive Priority	Measure	Capability	Gap	Action
Low-cost operations	■ Cost per billing statement ■ Weekly postage	■ $0.0813 ■ $17,000	■ Target is $0.06 ■ Target is $14,000	■ Eliminate microfilming and storage of billing statements ■ Develop Web-based process for posting bills
Consistent quality	■ Percent errors in bill information ■ Percent errors in posting payments	■ 0.90% ■ 0.74%	■ Acceptable ■ Acceptable	■ No action ■ No action
Delivery speed	■ Lead time to process merchant payments	■ 48 hours	■ Acceptable	■ No action
Volume flexibility	■ Utilization	■ 98%	■ Too high to support rapid increase in volumes	■ Acquire temporary employees ■ Improve work methods

Is the billing and payment process up to the competitive challenge? Table 1.5 shows how to match capabilities to priorities and uncover any gaps in the credit card division's operations strategy. The procedure for assessing an operations strategy begins with identifying good measures for each priority. The more quantitative the measures are, the better. Data are gathered for each measure to determine the current capabilities of the process. Gaps are identified by comparing each capability to management's target values for the measures, and unacceptable gaps are closed by appropriate actions.

The credit card division shows significant gaps in the process's capability for low-cost operations. Management's remedy is to redesign the process in ways that reduce costs but will not impair the other competitive priorities. Likewise, for volume flexibility, management realized that a high level of utilization is not conducive for processing quick surges in volumes while maintaining delivery speed. The recommended actions will help build a capability for meeting more volatile demands.

Addressing the Trends and Challenges in Operations Management

Several trends are currently having a great impact on operations management: productivity improvement; global competition; and ethical, workforce diversity, and environmental issues. Accelerating change in the form of information technology, e-commerce, robotics, and the Internet is dramatically affecting the design of new services and products as well as a firm's sales, order fulfillment, and purchasing processes. In this section, we look at these trends and their challenges for operations managers.

Productivity Improvement

Productivity is a basic measure of performance for economies, industries, firms, and processes. Improving productivity is a major trend in operations management because all firms face pressures to improve their processes and supply chains so as to compete with their domestic and foreign competitors. **Productivity** is the value of outputs (services and products) produced divided by the values of input resources (wages, cost of equipment, etc.) used:

productivity

The value of outputs (services and products) produced divided by the values of input resources (wages, costs of equipment, etc.).

$$\text{Productivity} = \frac{\text{Output}}{\text{Input}}$$

Manufacturing employment peaked at just below 20 million in mid-1979, and shrunk by nearly 8 million from 1979 to 2011.[2] However, the manufacturing productivity in the United States has climbed steadily, as more manufacturing capacity and output has been achieved efficiently with a leaner work force. It is interesting and even surprising to compare productivity improvements in the service and manufacturing sectors. In the United States, employment in the service sector has grown rapidly, outstripping the manufacturing sector. It now employs about 90 percent of the workforce. But service-sector

[2]Paul Wiseman, "Despite China's Might, US Factories Maintain Edge," *The State* and *The Associated Press* (January 31, 2011).

productivity gains have been much lower. If productivity growth in the service sector stagnates, so does the overall standard of living regardless of which part of the world you live in. Other major industrial countries, such as Japan and Germany, are experiencing the same problem. Yet signs of improvement are appearing. The surge of investment across national boundaries can stimulate productivity gains by exposing firms to greater competition. Increased investment in information technology by service providers also increases productivity.

Measuring Productivity As a manager, how do you measure the productivity of your processes? Many measures are available. For example, value of output can be measured by what the customer pays or simply by the number of units produced or customers served. The value of inputs can be judged by their cost or simply by the number of hours worked.

Managers usually pick several reasonable measures and monitor trends to spot areas needing improvement. For example, a manager at an insurance firm might measure office productivity as the number of insurance policies processed per employee per week. A manager at a carpet company might measure the productivity of installers as the number of square yards of carpet installed per hour. Both measures reflect *labor productivity*, which is an index of the output per person or per hour worked. Similar measures may be used for *machine productivity*, where the denominator is the number of machines. Accounting for several inputs simultaneously is also possible. *Multifactor productivity* is an index of the output provided by more than one of the resources used in production; it may be the value of the output divided by the sum of labor, materials, and overhead costs. Here is an example:

EXAMPLE 1.1 Productivity Calculations

Calculate the productivity for the following operations:

a. Three employees process 600 insurance policies in a week. They work 8 hours per day, 5 days per week.

b. A team of workers makes 400 units of a product, which is sold in the market for $10 each. The accounting department reports that for this job the actual costs are $400 for labor, $1,000 for materials, and $300 for overhead.

MyOMLab

Tutor 1.1 in MyOMLab provides a new example for calculating productivity.

SOLUTION

a.
$$\text{Labor productivity} = \frac{\text{Policies processed}}{\text{Employee hours}}$$
$$= \frac{\text{600 policies}}{(\text{3 employees})(\text{40 hours/employee})} = \mathbf{5}\ \text{policies/hour}$$

b.
$$\text{Multifactor productivity} = \frac{\text{Value of output}}{\text{Labor cost} + \text{Materials cost} + \text{Overhead cost}}$$
$$= \frac{(\text{400 units})(\$10/\text{unit})}{\$400 + \$1{,}000 + \$300} = \frac{\$4{,}000}{\$1{,}700} = \mathbf{2.35}$$

DECISION POINT

We want multifactor productivity to be as high as possible. These measures must be compared with performance levels in prior periods and with future goals. If they do not live up to expectations, the process should be investigated for improvement opportunities.

The Role of Management The way processes are managed plays a key role in productivity improvement. Managers must examine productivity from the level of the supply chain because it is the collective performance of individual processes that makes the difference. The challenge is to increase the value of output relative to the cost of input. If processes can generate more output or output of better quality using the same amount of input, productivity increases. If they can maintain the same level of output while reducing the use of resources, productivity also increases.

Global Competition

Most businesses realize that, to prosper, they must view customers, suppliers, facility locations, and competitors in global terms. Firms have found that they can increase their market penetration by locating their production facilities in foreign countries because it gives them a local presence that reduces customer

wsr/Alamy

Sonoco is a global supplier of innovative packaging solutions including packages for Chips Ahoy cookies, M&M's, Pringles Potato Crisps, flexible brick packs for coffee, and many other products.

aversion to buying imports. Globalization also allows firms to balance cash flows from other regions of the world when economic conditions are less robust in the home country. Sonoco, a $5-billion-a-year industrial and consumer packaging company in Hartsville, South Carolina, has nearly 20,000 employees in 335 locations worldwide spread across 33 countries. These global operations resulted in international sales and income growth even as domestic sales were stumbling during 2007. How did Sonoco do it?[3] Locating operations in countries with favorable tax laws is one reason. Lower tax rates in Italy and Canada helped in padding the earnings margin. Another reason was a weak dollar, whereby a $46 million boost came from turning foreign currencies into dollars as Sonoco exported such items as snack bag packaging, and tubes and cores used to hold tape and textiles, to operations it owned in foreign countries. The exchange rate difference was more than enough to counter the added expense of increased raw materials, shipping, and energy costs in the United States.

Most products today are composites of materials and services from all over the world. Your Gap polo shirt is sewn in Honduras from cloth cut in the United States. Sitting in a Cineplex theater (Canadian), you munch a Nestle's Crunch bar (Swiss) while watching a Columbia Pictures movie (Japanese). Five developments spurred the need for sound global strategies: (1) improved transportation and communications technologies; (2) loosened regulations on financial institutions; (3) increased demand for imported services and goods; (4) reduced import quotas and other international trade barriers due to the formation of regional trading blocks, such as the European Union (EU) and the North American Free Trade Agreement (NAFTA); and (5) comparative cost advantages.

Comparative Cost Advantages China and India have traditionally been the sources for low-cost, but skilled, labor, even though the cost advantage is diminishing as these countries become economically stronger. In the late 1990s, companies manufactured products in China to grab a foothold in a huge market, or to get cheap labor to produce low-tech products despite doubts about the quality of the workforce and poor roads and rail systems. Today, however, China's new factories, such as those in the Pudong industrial zone in Shanghai, produce a wide variety of products that are sold overseas in the United States and other regions of the world. U.S. manufacturers have increasingly abandoned low profit margin sectors like consumer electronics, shoes, and toys to emerging nations such as China and Indonesia. Instead, they are focusing on making expensive goods like computer chips, advanced machinery, and health care products that are complex and which require specialized labor.

Foreign companies have opened tens of thousands of new facilities in China over the past decade. Many goods the United States imports from China now come from foreign-owned companies with operations there. These companies include telephone makers, such as Nokia and Motorola, and nearly all of the big footwear and clothing brands. Many more major manufacturers are there as well. The implications for competition are enormous. Companies that do not have operations in China are finding it difficult to compete on the basis of low prices with companies that do. Instead, they must focus on speed and small production runs.

What China is to manufacturing, India is to service. As with the manufacturing companies, the cost of labor is a key factor. Indian software companies have grown sophisticated in their applications and offer a big advantage in cost. The computer services industry is also affected. Back-office operations are affected for the same reason. Many firms are using Indian companies for accounting and bookkeeping, preparing tax returns, and processing insurance claims. Many tech companies, such as Intel and Microsoft, are opening significant research and development (R&D) operations in India.

[3]Ben Werner, "Sonoco Holding Its Own," *The State* (February 7, 2008); **http://www.sonoco.com**, 2008.

Disadvantages of Globalization Of course, operations in other countries can have disadvantages. A firm may have to relinquish proprietary technology if it turns over some of its component manufacturing to offshore suppliers or if suppliers need the firm's technology to achieve desired quality and cost goals. Political risks may also be involved. Each nation can exercise its sovereignty over the people and property within its borders. The extreme case is nationalization, in which a government may take over a firm's assets without paying compensation. Exxon and other large multinational oil firms are scaling back operations in Venezuela due to nationalization concerns. Further, a firm may actually alienate customers back home if jobs are lost to offshore operations.

Employee skills may be lower in foreign countries, requiring additional training time. South Korean firms moved much of their sports shoe production to low-wage Indonesia and China, but they still manufacture hiking shoes and in-line roller skates in South Korea because of the greater skills required. In addition, when a firm's operations are scattered globally, customer response times can be longer. We discuss these issues in more depth in Chapter 12, "Designing Effective Supply Chains," because they should be considered when making decisions about outsourcing. Coordinating components from a wide array of suppliers can be challenging. In addition, as Managerial Practice 1.1 shows, catastrophic events such as the Japanese earthquake affect production and operations in Europe and United States because connected supply chains can spread disruptions rapidly and quickly across international borders.

MANAGERIAL PRACTICE 1.1 Japanese Earthquake and Its Supply Chain Impact


Dario Mitidieri/Getty Images

Devastation caused by the strong earthquake in Kobe, the sixth-largest city in Japan located approximately 19 miles west of Osaka on the north shore of Osaka Bay.

Northeast Touhoku district of Japan was struck by a set of massive earthquakes on the afternoon of March 11, 2011, which were soon followed by a huge tsunami that sent waves higher than 33 feet in the port city of Sendai 80 miles away and traveling at the speed of a jetliner. At nearly 9.0 on the Richter scale, it was one of the largest recorded earthquakes to hit Japan. It shifted the Earth's axis by 6 inches with an impact that was felt 250 miles inland in Tokyo, and which moved Eastern Japan 13 feet toward North America. Apart from huge loss of life and hazards of nuclear radiation arising from the crippled Daiichi nuclear reactors in Fukushima, the damage to the manufacturing plants in Japan exposed the hazards of interconnected global supply chains and their impact on factories located half way around the globe.

The impact of the earthquake was particularly acute on industries that rely on cutting edge electronic parts sourced from Japan. Shin-Etsu Chemical Company is the world's largest producer of silicon wafers and supplies 20 percent of the global capacity. Its centralized plant located 40 miles from the Fukushima nuclear facility was damaged in the earthquake, causing ripple effects at Intel and Toshiba that purchase wafers from Shin-Etsu. Similarly, a shortage of automotive sensors from Hitachi slowed or halted production of vehicles in Germany, Spain, and France, while Chrysler reduced overtime at factories in Mexico and Canada to conserve parts from Japan. Even worse, General Motors stopped production altogether at a plant in Louisiana and Ford closed a truck plant in Kentucky due to the quake. The supply of vehicles such as Toyota's Prius and Lexus were limited in the United States because of production disruptions in its Japanese factories. China was affected too, where ZTE Corporation faced shortages of batteries and LCD screens for its cell phones. Similarly, Lenovo in China faced reduced supplies of components from Japan for assembly of its tablet computers. These disruptions due to reliance on small concentrated network of suppliers in Japan and globally connected production and logistics systems have caused worker layoffs an increase in prices of affected products, and economic losses that have been felt around the world.

Sources: Don Lee and David Pearson, "Disaster in Japan Exposes Supply Chain Weakness," *The State* (April 8, 2011), B6-B7; "Chrysler Reduces Overtime to Help Japan," *The Associated Press* (April 8, 2011) printed in *The State* (April 6, 2011), B7; Krishna Dhir, "From the Editor," *Decision Line*, vol. 42, no. 2, 3.

Strong global competition affects industries everywhere. For example, U.S. manufacturers of steel, appliances, household durable goods, machinery, and chemicals have seen their market share decline in both domestic and international markets. With the value of world trade in commercial services now at more than $4.3 trillion per year, banking, data processing, airlines, and consulting services are beginning to face many of the same international pressures. Regional trading blocs, such as EU and NAFTA, further change the competitive landscape in both services and manufacturing. Regardless of which area of the world you live in, the challenge is to produce services or products that can compete in a global market and to design the processes that can make it happen.

Weng lei/AP Photos

A Chinese consumer looks at Timberland products at a department store in Shanghai, China, November 11, 2010. Timberland seeks to benefit from rising incomes in the worlds fastest-growing major economy, and will also invest in its Hong Kong shops.

Ethical, Workforce Diversity, and Environmental Issues

Businesses face more ethical quandaries than ever before, intensified by an increasing global presence and rapid technological change. As companies locate new operations and acquire more suppliers and customers in other countries, potential ethical dilemmas arise when business is conducted by different rules. Some countries are more sensitive than others about conflicts of interest, bribery, discrimination against minorities and women, minimum-wage levels, and unsafe workplaces. Managers must decide whether to design and operate processes that do more than just meet local standards. In addition, technological change brings debates about data protection and customer privacy. In an electronic world, businesses are geographically far from their customers, so a reputation of trust is paramount.

In the past, many people viewed environmental problems, such as toxic waste, poisoned drinking water, poor air quality, and climate change as quality-of-life issues; now, many people and businesses see them as survival issues. The automobile industry has seen innovation in electric and hybrid cars in response to environmental concerns and economic benefits arising from using less expensive fuels. Industrial nations face a particular burden because their combined populations consume proportionally much larger resources. Just seven nations, including the United States and Japan, produce almost half of all greenhouse gases. Now China and India have added to that total carbon footprint because of their vast economic and manufacturing expansion over the past decade.

Apart from government initiatives, large multinational companies have a responsibility as well for creating environmentally conscious practices, and can do so profitably. For instance, Timberland has over 110 stores in China because of strong demand for its boots, shoes, clothes, and outdoor gear in that country. It highlights its environmental credentials and corporate social responsibility through investments such as the reforestation efforts in northern China's Horqin Desert. Timberland hopes to double the number of stores over the next 3 years by environmentally differentiating itself from the competition. We discuss these issues in greater detail in Chapter 15, "Managing Supply Chain Sustainability."

The challenge is clear: Issues of ethics, workforce diversity, and the environment are becoming part of every manager's job. When designing and operating processes, managers should consider integrity, respect for the individual, and customer satisfaction along with more conventional performance measures such as productivity, quality, cost, and profit.

→ **Using Operations to Create Value**

PROCESS MANAGEMENT

Process Strategy and Analysis
Managing Quality
Planning Capacity
Managing Process Constraints
Designing Lean Systems
Managing Effective Projects

CUSTOMER DEMAND MANAGEMENT

Forecasting Demand
Managing Inventories
Planning and Scheduling Operations
Efficient Resource Planning

SUPPLY CHAIN MANAGEMENT

Designing Effective Supply Chains
Supply Chains and Logistics
Integrating the Supply Chain
Managing Supply Chain Sustainability

▲ **FIGURE 1.7**
Managing Processes, Customer Demand, and Supply Chains

Designing and Operating Processes and Supply Chains

How can firms meet challenges today and in the future to adequately recognize these trends and take advantage of opportunities in a global market place? One way is to recognize challenges as opportunities to improve existing processes and supply chains or to create new, innovative ones. The management of processes and supply chains goes beyond designing them; it requires the ability to ensure they achieve their goals. Firms should manage their processes and supply chains to maximize their competitiveness in the markets they serve. We share this philosophy of operations management, as illustrated in Figure 1.7. We use this figure at the start of each chapter to show how the topic of the chapter fits into our philosophy of operations management. In addition, this text also contains several chapter supplements that are not explicitly shown in Figure 1.7.

Figure 1.7 shows that all effective operations decisions follow from a sound operations strategy. Consequently, our text has three major parts: "Part 1: Process Management," Part 2: "Customer Demand Management," and "Part 3: Supply Chain Management." The flow of topics reflects our approach of first understanding how a firm's operations can help provide a solid foundation for competitiveness before tackling the essential process design decisions that will support its strategies. Each part begins with a strategy discussion to support the decisions in that part. Once it is clear how firms design and improve processes, we try to understand how they implement those designs to satisfactorily meet customer demand. Finally we examine the design and operation of supply chains that link processes, whether they are internal or external to the firm. The performance of the supply chains determines the firm's outcomes, which include the services or products the firm produces, the financial results, and feedback from the firm's customers. These outcomes, which are considered in the firm's strategic plan, are discussed throughout this text.

Part 1: Process Management In Part 1, we focus on analyzing processes and how they can be improved to meet the goals of the operations strategy. We begin by addressing the strategic aspects of process design and then present a six-step systematic approach to process analysis. Each chapter in this part deals with some aspect of that approach. We discuss the tools that help managers analyze processes, and we reveal the methods firms use to measure process performance and quality. These methods provide the foundation for programs such as Six Sigma and total quality management. We also look at long-term capacity planning of firms, and shorter-term tactical decisions aimed at better identification and management of system constraints and bottlenecks.

Determining the best process capacity with effective constraint management and making processes "lean" by eliminating activities that do not add value while improving those that do are also key decisions in the redesign of processes. The activities involved in managing processes are essential for providing significant benefits to the firm. Effective management of its processes can allow a firm to reduce its costs and also increase customer satisfaction.

The concluding chapter of Part 1 is a discussion of the methods and tools of project management. Project management is an effective approach to implementing operations strategy through the introduction of new services or products as well as any changes to a firm's processes or supply chains.

Part 2: Customer Demand Management The focus of this part of the book is on effectively forecasting and managing customer demand. Therefore we begin by taking a look at forecasting methods and their accuracy, followed by managing inventory such that enough is kept on hand for satisfying customer demand but without tying up excessive resources in it. We follow that with chapters focused on two key planning activities for the effective operations (1) operations planning and scheduling, and (2) resource planning. Together, these planning activities allow for the creation of goods and services that would meet customer demand in a cost effective fashion.

Part 3: Supply Chain Management The focus of Part 3 is on supply chains involving processes both internal and external to the firm and the tools that enhance their execution. We follow that with understanding how the design of supply chains and major strategic decisions, such as outsourcing and locating facilities affect performance. We also look at contemporary issues surrounding supply chain integration and the impact of supply chains on the environment.

Adding Value with Process Innovation

It is important to note that the effective operation of a firm and its supply chain is as important as the design and implementation of its processes. Process innovation can make a big difference even in a low-growth industry. Examining processes from the perspective of the value they add is an important part of a successful manager's agenda, as is gaining an understanding of how core processes and related supply chains are linked to their competitive priorities, markets, and the operations strategy of a firm. Who says operations management does not make a difference?

David Adame/AP Images

Via operational innovations that add value to its products, and catchy promotional advertisements, Progressive Insurance has been able to achieve amazing growth in a low-growth industry.

In the long run, the operations manager's decisions should reflect corporate strategy. At the strategic level, operations managers are involved in the development of new capabilities and the maintenance of existing capabilities to best serve the firm's external customers. Operations managers design new processes that have strategic implications, and they are deeply involved in the development and organization of supply chains that link external suppliers and external customers to the firm's internal processes. Operations managers are often responsible for key performance measures such as cost and quality. These decisions have strategic impact because they affect the processes the firm uses to gain a competitive edge.

Plans, policies, and actions should be linked to those in other functional areas to support the firm's overall goals and objectives. Taking a process view of a firm facilitates these links. Regardless of whether you aspire to be an operations manager, or you just want to use the principles of operations management to become a more effective manager, remember that effective management of people, capital, information, and materials is critical to the success of any process and any supply chain.

As you study operations management, keep two principles in mind:

1. Each part of an organization, not just the operations function, must design and operate processes that are part of a supply chain and deal with quality, technology, and staffing issues.
2. Each function of an organization has its own identity and yet is connected with operations through shared processes.

Great strategic decisions lead nowhere if the tactical decisions that support them are wrong. Operations managers are also involved in tactical decisions, including process improvement and performance measurement, managing and planning projects, generating production and staffing plans, managing inventories, and scheduling resources. You will find numerous examples of these decisions, and the implications of making them, throughout this text. You will also learn about the decision-making tools practicing managers use to recognize and define the problem and then choose the best solution. The topics in this text will help you meet operations challenges and achieve operational innovation regardless of your chosen career path.

LEARNING GOALS IN REVIEW

Learning Goal	Guidelines for Review	MyOMLab Resources
1 Describe the role of operations in an organization and its historical evolution over time.	The section "Role of Operations in an Organization," pp. 23–24, shows how different functional areas of business come together to create value for a firm.	
2 Describe the process view of operations in terms of inputs, processes, outputs, information flows, suppliers, and customers.	See the section "A Process View," pp. 24–26, which focuses on how nested and other processes work. Understand the key differences between manufacturing and service processes. Review Figure 1.2 for the important inputs, outputs, and information flows associated with any process.	
3 Describe the supply chain view of operations in terms of linkages between core and support processes.	Review Figure 1.4 for the important supply chain linkage and information flows.	
4 Define an operations strategy and its linkage to corporate strategy and market analysis.	See the section on "Operations Strategy" and sub-section on "Corporate Strategy," pp. 28–31, and review Figure 1.5.	
5 Identify nine competitive priorities used in operations strategy, and explain how a consistent pattern of decisions can develop organizational capabilities.	The section "Competitive Priorities and Capabilities," pp. 31–36, discusses the important concept of order winners and qualifiers. Review Table 1.3 for important illustrations and examples of how leading edge firms implemented different competitive priorities to create a unique positioning in the marketplace. Review Table 1.5 that provides a nice illustrative example of how firms must identify gaps in their competitive priorities and build capabilities through related process and operational changes.	
6 Identify the latest trends in operations management, and understand how given these trends, firms can address the challenges facing operations and supply chain managers in a firm.	The section "Addressing the Trends and Challenges in Operations Management," pp. 36–42, describes the pressures managers face for achieving productivity improvements, along with managing sustainability and work force diversity related issues in the face of global competition. Also review the section "Adding Value with Process Innovation" on p. 41.	**OM Explorer Tutor:** Productivity Measures **Active Model Exercise:** Productivity

Key Equations

Addressing the Trends and Challenges in Operations Management

1. Productivity is the ratio of output to input:

$$\text{Productivity} = \frac{\text{Output}}{\text{Input}}$$

Key Terms

competitive capabilities 31
competitive priorities 31
consistent quality 32
core competencies 30
core process 27
customer relationship process 27
customization 32
delivery speed 32
development speed 32
external customers 25
external suppliers 25
internal customers 25
internal suppliers 25
lead time 30
low-cost operations 32
nested process 25
new service/product development process 27
on-time delivery 32
operation 23
operations management 23
operations strategy 28
order fulfillment process 27
order qualifier 33
order winner 33
process 23
productivity 36
supplier relationship process 27
supply chain 23
supply chain management 23
supply chain processes 28
support process 27
time-based competition 33
top quality 32
variety 32
volume flexibility 32

Solved Problem 1

MyOMLab Video

Student tuition at Boehring University is $150 per semester credit hour. The state supplements school revenue by $100 per semester credit hour. Average class size for a typical 3-credit course is 50 students. Labor costs are $4,000 per class, materials costs are $20 per student per class, and overhead costs are $25,000 per class.

a. What is the *multifactor* productivity ratio for this course process?

b. If instructors work an average of 14 hours per week for 16 weeks for each 3-credit class of 50 students, what is the *labor* productivity ratio?

SOLUTION

a. Multifactor productivity is the ratio of the value of output to the value of input resources.

$$\begin{aligned}
\text{Value of output} &= \left(\frac{50 \text{ students}}{\text{class}}\right)\left(\frac{3 \text{ credit hours}}{\text{students}}\right)\left(\frac{\$150 \text{ tuition} + \$100 \text{ state support}}{\text{credit hour}}\right) \\
&= \$37{,}500/\text{class} \\
\text{Value of inputs} &= \text{Labor} + \text{Materials} + \text{Overhead} \\
&= \$4{,}000 + (\$20/\text{student} \times 50 \text{ students/class}) + \$25{,}000 \\
&= \$30{,}000/\text{class} \\
\begin{array}{r}\text{Multifactor} \\ \text{productivity}\end{array} &= \frac{\text{Output}}{\text{Input}} = \frac{\$37{,}500/\text{class}}{\$30{,}000/\text{class}} = \mathbf{1.25}
\end{aligned}$$

b. Labor productivity is the ratio of the value of output to labor hours. The value of output is the same as in part (a), or $37,500/class, so

$$\begin{aligned}
\text{Labor hours of input} &= \left(\frac{14 \text{ hours}}{\text{week}}\right)\left(\frac{16 \text{ weeks}}{\text{class}}\right) = 224 \text{ hours/class} \\
\text{Labor productivity} &= \frac{\text{Output}}{\text{Input}} = \frac{\$37{,}500/\text{class}}{224 \text{ hours/class}} \\
&= \mathbf{\$167.41}/\text{hour}
\end{aligned}$$

Solved Problem 2

Natalie Attire makes fashionable garments. During a particular week, employees worked 360 hours to produce a batch of 132 garments, of which 52 were "seconds" (meaning that they were flawed). Seconds are sold for $90 each at Attire's Factory Outlet Store. The remaining 80 garments are sold to retail distribution at $200 each. What is the *labor* productivity ratio of this manufacturing process?

SOLUTION

$$\begin{aligned}
\text{Value of output} &= (52 \text{ defective} \times \$90/\text{defective}) + (80 \text{ garments} \times \$200/\text{garment}) \\
&= \$20{,}680 \\
\text{Labor hours of input} &= 360 \text{ hours} \\
\text{Labor productivity} &= \frac{\text{Output}}{\text{Input}} = \frac{\$20{,}680}{360 \text{ hours}} \\
&= \mathbf{\$57.44} \text{ in sales per hour}
\end{aligned}$$

Discussion Questions

1. Consider your last (or current) job.
   - **a.** What activities did you perform?
   - **b.** Who were your customers (internal and external), and how did you interact with them?
   - **c.** How could you measure the customer value you were adding by performing your activities?
   - **d.** Was your position in accounting, finance, human resources, management information systems, marketing, operations, or other? Explain.
2. Consider amazon.com, whose Web site enjoys millions of "hits" each day and puts customers in touch with millions of services and products. What are amazon.com's competitive priorities and what should its operations strategy focus on?
3. A local hospital declares that it is committed to provide *care* to patients arriving at the emergency unit in less than 15 minutes and that it will never turn away patients who need to be hospitalized for further medical care. What implications does this commitment have for strategic operations management decisions (i.e., decisions relating to capacity and workforce)?
4. FedEx built its business on quick, dependable delivery of items being shipped by air from one business to another. Its early advantages included global tracking of shipments using Web technology. The advancement of Internet technology enabled competitors to become much more sophisticated in order tracking. In addition, the advent of Web-based businesses put pressure on increased ground transportation deliveries. Explain how this change in the environment has affected FedEx's operations strategy, especially relative to UPS, which has a strong hold on the business-to-consumer ground delivery business.
5. Suppose that you were conducting a market analysis for a new textbook about technology management. What would you need to know to identify a market segment? How would you make a needs assessment? What should be the collection of services and products?
6. Although all nine of the competitive priorities discussed in this chapter are relevant to a company's success in the marketplace, explain why a company should not necessarily try to excel in all of them. What determines the choice of the competitive priorities that a company should emphasize for its key processes?
7. Choosing which processes are core to a firm's competitive position is a key strategic decision. For example, Nike, a popular sports shoe company, focuses on the customer relationship, new product development, and supplier relationship processes and leaves the order fulfillment process to others. Allen Edmonds, a top-quality shoe company, considers all four processes to be core processes. What considerations would you make in determining which processes should be core to your manufacturing company?
8. A local fast-food restaurant processes several customer orders at once. Service clerks cross paths, sometimes nearly colliding, while they trace different paths to fill customer orders. If customers order a special combination of toppings on their hamburgers, they must wait quite some time while the special order is cooked. How would you modify the restaurant's operations to achieve competitive advantage? Because demand surges at lunchtime, volume flexibility is a competitive priority in the fast-food business. How would you achieve volume flexibility?
9. Satory Malaysia Food & Beverage is the Malaysian subsidiary of a big Japanese keiretsu, Satori Kohei, which has its core business in the food and beverage sector. Satory Malaysia—which only deals in dairy products, prepared food and soft drinks—is a medium-sized company based in Johor Baru, with a secondary plant in Singapore. It employs about 50,000 people across the two locations. The company has faced some difficult times due to the global economic crisis and, to address the declining profit, has decided to diversify its core business.
   - **a.** What types of strategic plans should Satory Malaysia make, and in which sectors should it consider expanding its activity?
   - **b.** What environmental forces should Satory Malaysia consider before making its decisions?
   - **c.** What are the core competencies of Satory that are going to affect its plans?
10. Founded in 2001, Ruisheng Microtech Shenzhen is a software developing company based in Shenzhen, China. It produces third-party software for bigger contractors like Huawei and other Chinese companies in the same sector. Until recently, business has always gone quite well due to its high-quality service and the company's diligence to keep to the tight deadlines, like those imposed in the IT sector. However, a series of issues in the latest programs that Ruisheng sold attracted various complaints and requests for modifications. Some of Ruisheng's contractors threatened to shift to its competitors in the same area, despite the goodwill shared between the companies, and Ruisheng has been given only a few weeks to address and resolve the issues. The company's general manager is now facing some complex decisions in order to solve this impasse and reclaim its former customer-satisfaction levels.
    - **a.** What types of strategic plans can Ruisheng make to address its quality issues?

b. What environmental factors need to be taken into consideration when previewing changes in its corporate's strategy?

c. What are the possible distinctive competencies of Ruisheng and how they get into play in this case to company's advantage?

11. You are designing a grocery delivery business. Via the Internet, your company will offer staples and frozen foods in a large metropolitan area and then deliver them within a customer-defined window of time. You plan to partner with two major food stores in the area. What should be your competitive priorities and what capabilities do you want to develop in your core and support processes?

Problems

The OM Explorer and POM for Windows software is available to all students using the 11th edition of this textbook. Go to **http://www.pearsonglobaleditions.com/krajewski** to download these computer packages. If you purchased MyOMLab, you also have access to Active Models software and significant help in doing the following problems. Check with your instructor on how best to use these resources. In many cases, the instructor wants you to understand how to do the calculations by hand. At the least, the software provides a check on your calculations. When calculations are particularly complex and the goal is interpreting the results in making decision, the software entirely replaces the manual calculations.

Addressing the Trends and Challenges in Operations Management

1. (Refer to Solved Problem 1.) Coach Bjourn Toulouse led the Big Red Herrings to several disappointing football seasons. Only better recruiting will return the Big Red Herrings to winning form. Because of the current state of the program, Boehring University fans are unlikely to support increases in the $192 season ticket price. Improved recruitment will increase overhead costs to $30,000 per class section from the current $25,000 per class section. The university's budget plan is to cover recruitment costs by increasing the average class size to 75 students. Labor costs will increase to $6,500 per 3-credit course. Material costs will be about $25 per student for each 3-credit course. Tuition will be $200 per semester credit, which is supplemented by state support of $100 per semester credit.

a. What is the multifactor productivity ratio? Compared to the result obtained in Solved Problem 1, did productivity increase or decrease for the course process?

b. If instructors work an average of 20 hours per week for 16 weeks for each 3-credit class of 75 students, what is the *labor* productivity ratio?

2. Sud and Duds Laundry washed and pressed the following number of shirts per week:

Week	Work Crew	Total Hours	Shirts
1	Sud and Dud	26	71
2	Sud and Jud	43	136
3	Sud, Dud, and Jud	66	155
4	Sud, Dud, and Jud	55	123
5	Dud and Jud	42	136

a. Calculate the labor productivity per hour for each week.

b. Explain the labor productivity patter exhibited by the data.

3. Easy Electronics produces CD players using an automated assembly line process. The standard cost of CD players is $139 per unit (labor, $28; materials, $66; and overhead, $45). The sales price is $275 per unit.

a. To achieve a 12 percent multifactor productivity improvement by reducing materials costs only, by what percentage must these costs be reduced?

b. To achieve a 12 percent multifactor productivity improvement by reducing labor costs only, by what percentage must these costs be reduced?

c. To achieve a 12 percent multifactor productivity improvement by reducing overhead costs only, by what percentage must these costs be reduced?

4. At Symteks, the output of a process is valued at $90 per unit. The cost of labor is $45 per hour including benefits. The accounting department provided the following information about the process for the past four weeks:

	Week 1	Week 2	Week 3	Week 4
Units Produced	1,177	1,306	1,088	985
Labor ($)	12,375	14,892	10,563	9,576
Material ($)	20,577	24,573	20,492	18,364
Overhead ($)	9,151	10,480	8,686	7,798

a. Use the multifactor productivity ratio to see whether recent process improvements had any effect and, if so, when the effect was noticeable.

b. Has labor productivity changed? Use the labor productivity ratio to support your answer.

5. Alyssa's Custom Cakes currently sells 4 birthday, 3 wedding, and 2 specialty cakes each month for $45, $155, and $105 each, respectively. The cost of labor is $50 per hour (including benefits) and it takes 90 minutes to produce a birthday cake, 240 minutes to produce a wedding cake, and 60 minutes to produce a specialty cake. Alyssa's current multifactor productivity ratio is 1.30.

a. Use the multifactor productivity ratio provided to calculate the average cost of the cakes produced.

b. Calculate Alyssa's labor productivity ratio in dollars per hour for each type of cake.

c. Based solely on the labor productivity ratio, which cake should Alyssa try to sell the most?

d. Based on your answer in part (a), is there a type of cake Alyssa should stop selling?

6. The Big Black Bird Company (BBBC) has a large order for special plastic-lined military uniforms to be used in an urgent military operation. Working the normal two shifts of 40 hours each per week, the BBBC production process usually produces 2,500 uniforms per week at a standard cost of $140 each. 72 employees work the first shift and 28 employees work the second. The contract price is $240 per uniform. Due to the urgent need, BBBC is authorized to use around-the-clock production, six days per week. When each of the two shifts works 72 hours per week, production increases to 4,000 uniforms per week but at a cost of $152 each.

   a. Did the multifactor productivity ratio increase, decrease, or remain the same? If it changed, by what percentage did it change?

   b. Did the labor productivity ratio increase, decrease, or remain the same? If it changed, by what percentage did it change?

   c. Did weekly profits increase, decrease, or remain the same?

7. Mack's guitar fabrication shop produces low-cost, highly durable guitars for beginners. Typically, out of the 100 guitars that begin production each month, only 80 percent are considered good enough to sell. The other 20 percent are scrapped due to quality problems that are identified after they have completed the production process. Each guitar sells for $250. Because some of the production process is automated, each guitar only requires 10 labor hours. Each employee works an average 160 hours per month. Labor is paid at $10/hour, materials cost is $40/guitar, and overhead is $4,000.

   a. Calculate the labor and multifactor productivity ratios.

   b. After some study, the operations manager Darren Funk recommends three options to improve the company's multifactor productivity: (1) increase the sales price by 10 percent, (2) improve quality so that only 10 percent are defective, or (3) reduce labor, material, and overhead costs by 10 percent. Which option has the greatest impact on the multifactor productivity measure?

8. Mariah Enterprises makes a variety of consumer electronic products. Its camera manufacturing plant is considering choosing between two different processes, named Alpha and Beta, which can be used to make a component part. To make the correct decision, the managers would like to compare the labor and multifactor productivity of process Alpha with that of process Beta. The value of process output for Alpha and Beta is $150 and $160 per unit, and the corresponding overhead costs are $5,000 and $7,000, respectively.

	PROCESS ALPHA		PROCESS BETA	
Product	**A**	**B**	**A**	**B**
Output (units)	30	60	50	40
Labor ($)	1,200	1,400	1,000	2,000
Material ($)	1,400	3,000	2,500	1,500

   a. Which process, Alpha or Beta, is more productive?

   b. What conclusions can you draw from your analysis?

9. The Morning Brew Coffee Shop sells Regular, Cappuccino, and Vienna blends of coffee. The shop's current daily labor cost is $320, the equipment cost is $125, and the overhead cost is $225. Daily demands, along with selling price and material costs per beverage, are given below.

	Regular Coffee	Cappuccino	Vienna Coffee
Beverages sold	350	100	150
Price per beverage	$2.00	$3.00	$4.00
Material ($)	$0.50	$0.75	$1.25

Harald Luckerbauer, the manager at Morning Brew Coffee Shop, would like to understand how adding Eiskaffee (a German coffee beverage of chilled coffee, milk, sweetener, and vanilla ice cream) will alter the shop's productivity. His market research shows that Eiskaffee will bring in new customers and not cannibalize current demand. Assuming that the new equipment is purchased before Eiskaffee is added to the menu, Harald has developed new average daily demand and cost projections. The new equipment cost is $200, and the overhead cost is $350. Modified daily demands, as well as selling price and material costs per beverage for the new product line, are given below.

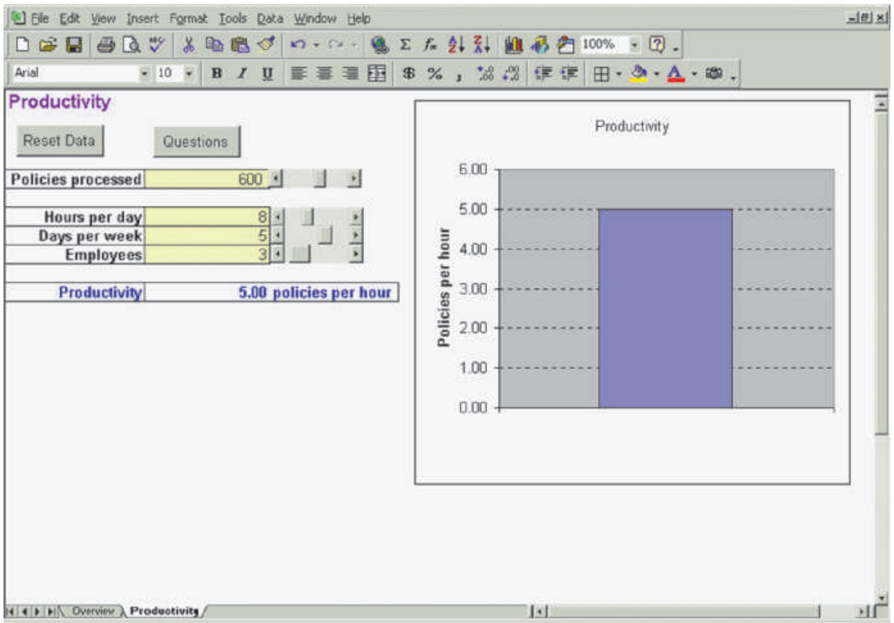
	Regular Coffee	Cappuccino	Vienna Coffee	Eiskaffee
Beverages sold	350	100	150	75
Price per beverage	$2.00	$3.00	$4.00	$5.00
Material ($)	$0.50	$0.75	$1.25	$1.50

   a. Calculate the change in labor and multifactor productivity if Eiskaffee is added to the menu.

   b. If everything else remains unchanged, how many units of Eiskaffee would have to be sold to ensure that the multifactor productivity increases from its current level?

Active Model Exercise

This Active Model appears in MyOMLab. It allows you to evaluate the important elements of labor productivity.



◀ **ACTIVE MODEL 1.1**
Labor Productivity Using Data from Example 1.1

QUESTIONS

1. If the insurance company can process 60 (10 percent) more policies per week, by what percentage will the productivity measure rise?
2. Suppose the 8-hour day includes a 45-minute lunch. What is the revised productivity measure, excluding lunch?
3. If an employee is hired, what will be the weekly number of policies processed if the productivity of five policies per hour is maintained?
4. Suppose that, during the summer, the company works for only 4 days per week. What will be the weekly number of policies processed if the productivity of five policies per hour is maintained?

VIDEO CASE Using Operations to Create Value at Crayola

Operations processes are at the heart of Crayola, the Easton, Pennsylvania maker of crayons, markers, and paints loved by children of all ages around the world. Since 1903, the company has been taking wax, dyes, and other raw materials and turning them into a colorful array of products sold through an extensive network of distributors and retailers such as Walmart and Target stores. Each day, the company produces 13 million crayons, 2 million markers, 500,000 jars of paint, 170,000 pounds of modeling compounds, and 22,000 Silly Putty© eggs from its three manufacturing plants.

Crayola derives much of its own inspiration and creativity by asking, “What would a kid do?”—especially when focusing on innovation. Not that kids have the knowledge to create complex systems and operational processes. Rather, the question leads to creative solutions by freeing employees to think about the company’s competitive priorities in new ways. In the supply chain, the company maintains five “pillars” of operational leadership. These pillars focus attention on differentiating the company on (1) innovation, (2) sustainability, (3) agility and resilience, (4) cost, and (5) quality and ethical responsibility.

The company has a history of innovation. They were the first to introduce an art education program called Dream-Makers, into the nation’s elementary schools. Washable markers and crayons also were firsts for the industry and continue to be best-sellers for the company. Recently, the language on crayon paper packaging changed to include three languages—French, English and Spanish—instead of one. This change alone saved $400,000 in paper and printing costs since the packaging could now be used across multiple markets.

Pearson

Crayola, headquartered in Pennsylvania, has become a leader in its industry by focusing on operational excellence and innovation.

In the area of sustainability, Crayola built a solar farm on a 20-acre site adjacent to its manufacturing plant in Easton. The farm produces enough energy to completely run the plant as well as the headquarters building nearby. The 850 million colored pencils produced each year only use reforested wood, with one tree planted for every tree harvested. Sourcing for paraffin wax used in crayons recently moved from Louisiana to western Pennsylvania, saving 5,000 barrels of oil annually related to wax transportation. All plastic components are made with recycled plastics. And any excess wax from the production of crayons is reintroduced into the manufacturing process so no waste is produced.

The company is aggressively pursuing new markets outside the United States. China's market of children ages 0–14 is larger than all the other global markets combined, with more than half the world's child population. Yet only 14 percent of the company's total sales come from international markets. So, particular attention is being devoted to growing the company's manufacturing and distribution presences there. As you can imagine, this means operations managers must think about how to grow the current supply chain beyond the boundaries of existing domestic and international borders if additional expansion is to occur.

QUESTIONS

1. Map Crayola's five pillars of operational leadership to the competitive priorities in Table 1.3.
2. Create an assessment of Crayola's competitive priorities as it relates to their Asian expansion plans.
3. Which of the competitive priorities might present the biggest challenge to Crayola as it expands internationally?

CASE Theorganicgrocer.com

Theorganicgrocer.com is an online supplier of organically produced fruit and vegetables. Clients within a 50 km radius of Bangor in Wales are promised next-day delivery at a time and place selected by the customer. Maria Heales, a joint owner says, "Our business has been based on market research. We've done a great deal of background work to ensure our business model works. All the early signs suggested that people would order online if the quality was good, payment was secure, the price was right and delivery could be trusted…. 'Dependability, reliability, timeliness, quality and price' were the words that sung out," she says. The service offering includes delivery, 9 A.M. to 9 P.M., six days a week; organic produce; and customer-specified date and time of delivery. All produce is direct from the market on the day of delivery from a chilled vehicle. The Web site is updated daily to reflect current price and in-season produce. "The key to our success," Maria says, "is the simplicity of use of our Web site."

Vehicle route planning ensures deliveries are optimized and aggregated stock ordering means only produce previously ordered by customers is purchased. Customers' payments are made online using a secure, encrypted facility administered by a national bank. "But our business has grown, so we need to expand capacity and capability. We are no longer a fruit and 'veg' stall online!" Maria's husband and business partner, Marcus, says. Their goal now is to expand their business to include regional franchising, product range expansion and, for example, birthday gifts, filled baskets, and ready-to-eat gourmet selections. Operating from a small "lock-up" unit on the fringe of town, expansion of the business would require considerable capital investment. Moreover, the operations of the future business will be more complex.

Currently, 95 percent of the customers are households, with the remainder being local restaurants. Approximately 20 percent of their customer base generates 80 percent of the profit. Theorganicgrocer.com has a financial system—a computer application that Marcus modified to meet its needs. A separate computer package generates advertising material and mail-outs. This tends to be done by Maria when time permits. However, there is little market information to support strategic operations planning. Much of Maria and Marcus's aspiration is based on the success of their current operations and the hope that the trend continues. Whilst there are several competitors supplying online vegetables, they do not offer organic products and they have limited products. They are, however, some 20 percent cheaper than Theorganicgrocer.com.

As business has grown, there have been complaints of damaged products, and growth in customers has caused the average on-time deliveries (plus or minus 20 minutes) to fall from 95 percent to 75 percent. All this, Maria and Marcus argue, is more reason for expanding the business.

Marcus enjoys the technical aspects of the online business, and spends much of his time modifying and improving the Web site. When necessary, he helps to consolidate customers' orders. "I think my time is better spent on Web site development," Marcus says; "It's critical for the business if it goes down or it isn't showing current product information, then sales are jeopardized." Presently, Maria takes responsibility for placing orders to their thirty suppliers. Maria and the delivery drivers pack customer orders into salvaged cardboard boxes that are of various sizes and often damaged. "But at least they are free!" she laughs.

QUESTIONS

1. What are the comparative operational differences of a conventional "bricks and mortar" grocery to an online operation? What are the comparative value chains for each system?
2. What are the key processes in the online operation?
3. Where are the possible operational problem areas of their online business, now and in the future?
4. What operational improvements need to be taken now to improve competitiveness?

Source: This fictional case was prepared by Dr. David Parker, The University of Queensland, Business School, as a basis of classroom discussion.

SUPPLEMENT

A

DECISION MAKING MODELS

Operations managers make many decisions as they manage processes and supply chains. Although the specifics of each situation vary, decision making generally involves the same basic steps: (1) recognize and clearly define the problem, (2) collect the information needed to analyze possible alternatives, and (3) choose and implement the most feasible alternative.

Sometimes, hard thinking in a quiet room is sufficient. At other times, interacting with others or using more formal procedures are needed. Here, we present four such formal procedures: break-even analysis, the preference matrix, decision theory, and the decision tree.

- Break-even analysis helps the manager identify how much change in volume or demand is necessary before a second alternative becomes better than the first alternative.
- The preference matrix helps a manager deal with multiple criteria that cannot be evaluated with a single measure of merit, such as total profit or cost.
- Decision theory helps the manager choose the best alternative when outcomes are uncertain.
- A decision tree helps the manager when decisions are made sequentially—when today's best decision depends on tomorrow's decisions and events.

Break-Even Analysis

To evaluate an idea for a new service or product, or to assess the performance of an existing one, determining the volume of sales at which the service or product breaks even is useful. The **break-even quantity** is the volume at which total revenues equal total costs. Use of this technique is known as **break-even analysis**. Break-even analysis can also be used to compare processes by finding the volume at which two different processes have equal total costs.

break-even quantity

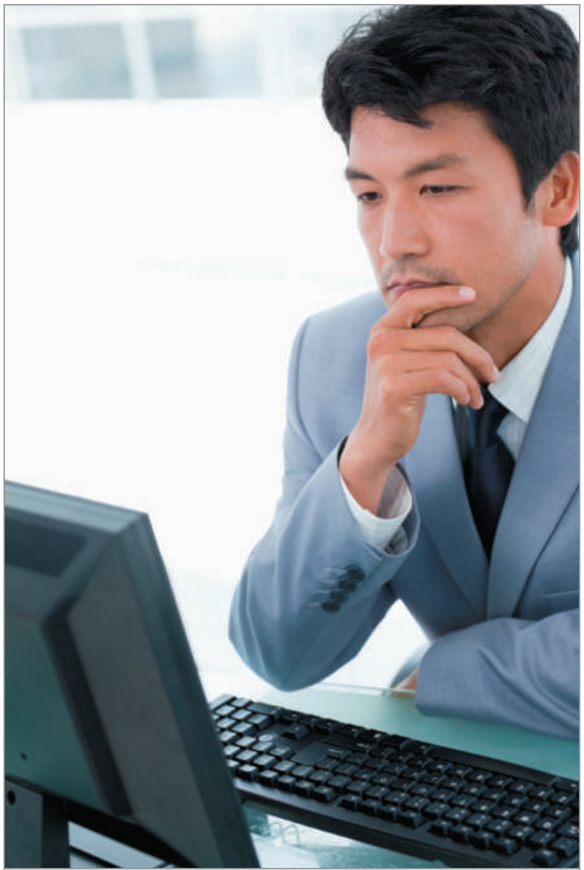
The volume at which total revenues equal total costs.

break-even analysis

The use of the break-even quantity; it can be used to compare processes by finding the volume at which two different processes have equal total costs.

LEARNING GOALS *After reading this supplement, you should be able to:*

1. Explain break-even analysis, using both the graphic and algebraic approaches.
2. Define and construct a preference matrix.
3. Explain how decision theory can be used to make decisions under conditions of certainty, uncertainty, and risk.
4. Describe how to draw and analyze a decision tree.



wavebreakmedia/Shutterstock

A manager is doing some hard thinking and analysis on his computer before reaching a final decision.

Evaluating Services or Products

We begin with the first purpose: to evaluate the profit potential of a new or existing service or product. This technique helps the manager answer questions, such as the following:

- Is the predicted sales volume of the service or product sufficient to break even (neither earning a profit nor sustaining a loss)?
- How low must the variable cost per unit be to break even, based on current prices and sales forecasts?
- How low must the fixed cost be to break even?
- How do price levels affect the break-even volume?

Break-even analysis is based on the assumption that all costs related to the production of a specific service or product can be divided into two categories: (1) variable costs and (2) fixed costs.

The **variable cost**, c, is the portion of the total cost that varies directly with volume of output: costs per unit for materials, labor, and usually some fraction of overhead. If we let Q equal the number of customers served or units produced per year, total variable cost $= cQ$. The **fixed cost**, F, is the portion of the total cost that remains constant regardless of changes in levels of output: the annual cost of renting or buying new equipment and facilities (including depreciation, interest, taxes, and insurance); salaries; utilities; and portions of the sales or advertising budget. Thus, the total cost of producing a service or good equals fixed costs plus variable costs multiplied by volume, or

$$\text{Total cost} = F + cQ$$

The variable cost per unit is assumed to be the same no matter how small or large Q is, and thus, total cost is linear. If we assume that all units produced are sold, total annual revenues equal revenue per unit sold, p, multiplied by the quantity sold, or

$$\text{Total revenue} = pQ$$

If we set total revenue equal to total cost, we get the break-even quantity point as

$$pQ = F + cQ$$
$$(p - c)Q = F$$
$$Q = \frac{F}{p - c}$$

variable cost

The portion of the total cost that varies directly with volume of output.

fixed cost

The portion of the total cost that remains constant regardless of changes in levels of output.

We can also find this break-even quantity graphically. Because both costs and revenues are linear relationships, the break-even quantity is where the total revenue line crosses the total cost line.

EXAMPLE A.1 Finding the Break-Even Quantity

MyOMLab

Active Model A.1 in MyOMLab provides additional insight on this break-even example and its extensions with four "what-if" questions.

MyOMLab

Tutor A.1 in MyOMLab provides a new example to practice break-even analysis.

A hospital is considering a new procedure to be offered at \$200 per patient. The fixed cost per year would be \$100,000, with total variable costs of \$100 per patient. What is the break-even quantity for this service? Use both algebraic and graphic approaches to get the answer.

SOLUTION

The formula for the break-even quantity yields

$$Q = \frac{F}{p - c} = \frac{100{,}000}{200 - 100} = 1{,}000 \text{ patients}$$

To solve graphically we plot two lines: one for costs and one for revenues. Two points determine a line, so we begin by calculating costs and revenues for two different output levels. The following table shows the results for $Q = 0$ and $Q = 2{,}000$. We selected zero as the first point because of the ease of plotting total revenue (0) and total cost (F). However, we could have used any two reasonably spaced output levels.

Quantity (patients) (Q)	Total Annual Cost (\$) (100,000 + 100Q)	Total Annual Revenue (\$) (200Q)
0	100,000	0
2,000	300,000	400,000

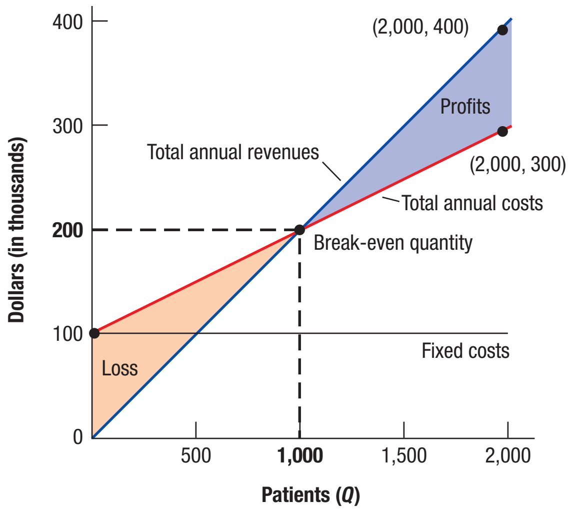


FIGURE A.1
Graphic Approach to Break-Even Analysis

We can now draw the cost line through points (0, 100,000) and (2,000, 300,000). The revenue line goes between (0, 0) and (2,000, 400,000). As Figure A.1 indicates, these two lines intersect at 1,000 patients, the break-even quantity.

DECISION POINT

Management expects the number of patients needing the new procedure will exceed the 1,000-patient break-even quantity but first wants to learn how sensitive the decision is to demand levels before making a final choice.

Break-even analysis cannot tell a manager whether to pursue a new service or product idea or drop an existing line. The technique can only show what is likely to happen for various forecasts of costs and sales volumes. To evaluate a variety of "what-if" questions, we use an approach called **sensitivity analysis**, a technique for systematically changing parameters in a model to determine the effects of such changes. The concept can be applied later to other techniques, such as linear programming. Here we assess the sensitivity of total profit to different pricing strategies, sales volume forecasts, or cost estimates.

sensitivity analysis
A technique for systematically changing parameters in a model to determine the effects of such changes.

EXAMPLE A.2 Sensitivity Analysis of Sales Forecasts

If the most pessimistic sales forecast for the proposed service in Figure A.1 were 1,500 patients, what would be the procedure's total contribution to profit and overhead per year?

SOLUTION

The graph shows that even the pessimistic forecast lies above the break-even volume, which is encouraging. The procedure's total contribution, found by subtracting total costs from total revenues, is

$$\begin{aligned} pQ - (F + cQ) &= 200(1{,}500) - [100{,}000 + 100(1{,}500)] \\ &= \$50{,}000 \end{aligned}$$

DECISION POINT

Even with the pessimistic forecast, the new procedure contributes \$50,000 per year. After evaluating the proposal with the present value method (see MyOMLab Supplement F), management added the new procedure to the hospital's services.

MyOMLab

Evaluating Processes

Often, choices must be made between two processes or between an internal process and buying services or materials on the outside. In such cases, we assume that the decision does not affect revenues. The manager must study all the costs and advantages of each approach. Rather than find the quantity at which total costs equal total revenues, the analyst finds the quantity for which the total costs for two alternatives are equal. For the make-or-buy decision, it is the quantity for which the total "buy" cost equals the total "make" cost. Let F_b equal the fixed cost (per year) of the buy option, F_m equal the fixed cost of the make option, c_b equal the variable cost (per unit) of the buy option, and c_m equal the variable cost of the make option. Thus, the total cost to buy is $F_b + c_bQ$ and the total cost to make is $F_m + c_mQ$. To find the break-even quantity, we set the two cost functions equal and solve for Q:

$$F_b + c_bQ = F_m + c_mQ$$

$$Q = \frac{F_m - F_b}{c_b - c_m}$$

The make option should be considered, ignoring qualitative factors, only if its variable costs are lower than those of the buy option. The reason is that the fixed costs for making the service or product are typically higher than the fixed costs for buying. Under these circumstances, the buy option is better if production volumes are less than the break-even quantity. Beyond that quantity, the make option becomes better. Chapter 12, "Designing Effective Supply Chains," brings out other considerations when making make-or-buy decisions.

EXAMPLE A.3

Break-Even Analysis for Make-or-Buy Decisions

MyOMLab

Active Model A.2 in MyOMLab provides additional insight on this make-or-buy example and its extensions.

The manager of a fast-food restaurant featuring hamburgers is adding salads to the menu. For each of the two new options, the price to the customer will be the same. The make option is to install a salad bar stocked with vegetables, fruits, and toppings and let the customer assemble the salad. The salad bar would have to be leased and a part-time employee hired. The manager estimates the fixed costs at \$12,000 and variable costs totaling \$1.50 per salad. The buy option is to have preassembled salads available for sale. They would be purchased from a local supplier at \$2.00 per salad. Offering preassembled salads would require installation and operation of additional refrigeration, with an annual fixed cost of \$2,400. The manager expects to sell 25,000 salads per year.

What is the make-or-buy quantity?

MyOMLab

Tutor A.2 in MyOMLab provides a new example to practice break-even analysis on make-or-buy decisions.

SOLUTION

The formula for the break-even quantity yields the following:

$$Q = \frac{F_m - F_b}{c_b - c_m}$$

$$= \frac{12{,}000 - 2{,}400}{2.0 - 1.5} = 19{,}200 \text{ salads}$$

FIGURE A.2 ▶

Break-Even Analysis Solver of OM Explorer for Example A.3

	Process 1	Process 2
Fixed costs (F)	\$12,000	\$2,400
Variable costs (c)	\$1.50	\$2.00
Expected demand	25,000	
Break-even quantity	19,200.0	
Decision: Process 1		

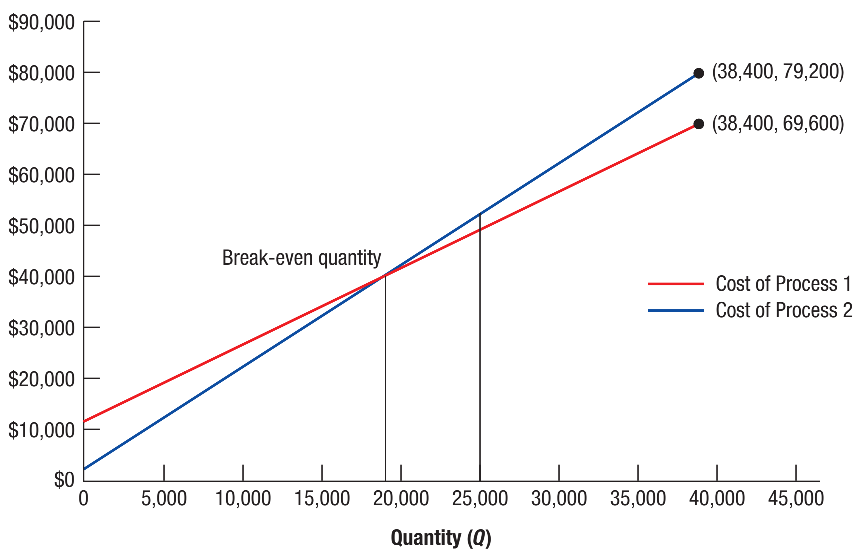


Figure A.2 shows the solution from OM Explorer's *Break-Even Analysis* Solver. The break-even quantity is 19,200 salads. As the 25,000-salad sales forecast exceeds this amount, the make option is preferred. Only if the restaurant expected to sell fewer than 19,200 salads would the buy option be better.

DECISION POINT

Management chose the make option after considering other qualitative factors, such as customer preferences and demand uncertainty. A deciding factor was that the 25,000-salad sales forecast is well above the 19,200-salad break-even quantity.


Ministr-84/Shutterstock

A drive-through only restaurant that does not have seating capacity will have lower fixed costs than a full service restaurant, and therefore will need a lower number of customers to reach the break-even point.

Preference Matrix

Decisions often must be made in situations where multiple criteria cannot be naturally merged into a single measure (such as dollars). For example, a manager deciding in which of two cities to locate a new plant would have to consider such unquantifiable factors as quality of life, worker attitudes toward work, and community reception in the two cities. These important factors cannot be ignored. A **preference matrix** is a table that allows the manager to rate an alternative according to several performance criteria. The criteria can be scored on any scale, such as from 1 (worst possible) to 10 (best possible) or from 0 to 1, as long as the same scale is applied to all the alternatives being compared. Each score is weighted according to its perceived importance, with the total of these weights typically equaling 100. The total score is the sum of the weighted scores (weight $\times$ score) for all the criteria. The manager can compare the scores for alternatives against one another or against a predetermined threshold. We use the preference matrix technique extensively in this text to address decisions where there are qualitative, as well as quantitative, factors to consider.

preference matrix
A table that allows the manager to rate an alternative according to several performance criteria.

EXAMPLE A.4 Evaluating an Alternative with a Preference Matrix

The following table shows the performance criteria, weights, and scores (1 = worst, 10 = best) for a new product: a thermal storage air conditioner. If management wants to introduce just one new product and the highest total score of any of the other product ideas is 800, should the firm pursue making the air conditioner?

MyOMLab
Tutor A.3 in MyOMLab provides a new example to practice with preference matrixes.

Performance Criterion	Weight (*A*)	Score (*B*)	Weighted Score (*A* × *B*)
Market potential	30	8	240
Unit profit margin	20	10	200
Operations compatibility	20	6	120
Competitive advantage	15	10	150
Investment requirement	10	2	20
Project risk	5	4	20
			Weighted score = 750

SOLUTION

Because the sum of the weighted scores is 750, it falls short of the score of 800 for another product. This result is confirmed by the output from OM Explorer's *Preference Matrix* Solver in Figure A.3.

FIGURE A.3 ▶
Preference Matrix Solver for Example A.4

Insert a Criterion | Add a Criterion | Remove a Criterion

	Weight (A)	Score (B)	Weighted Score (A x B)
Market potential	30	8	240
Unit profit margin	20	10	200
Operations compatability	20	6	120
Competitive advantage	15	10	150
Investment requirement	10	2	20
Project risk	5	4	20
		Final Weighted Score	750

DECISION POINT

Management should drop the thermal storage air-conditioner idea. Another new product idea is better, considering the multiple criteria, and management only wanted to introduce one new product at the time.

Not all managers are comfortable with the preference matrix technique. It requires the manager to state criteria weights before examining the alternatives, although the proper weights may not be readily apparent. Perhaps, only after seeing the scores for several alternatives can the manager decide what is important and what is not. Because a low score on one criterion can be compensated for or overridden by high scores on others, the preference matrix method also may cause managers to ignore important signals. In Example A.4, the investment required for the thermal storage air conditioner might exceed the firm's financial capability. In that case, the manager should not even be considering the alternative no matter how high its score.

Decision Theory

decision theory

A general approach to decision making when the outcomes associated with alternatives are often in doubt.

Decision theory is a general approach to decision making when the outcomes associated with alternatives are often in doubt. It helps operations managers with decisions on process, capacity, location, and inventory because such decisions are about an uncertain future. Decision theory can also be used by managers in other functional areas. With decision theory, a manager makes choices using the following process:

1. List the feasible *alternatives*. One alternative that should always be considered as a basis for reference is to do nothing. A basic assumption is that the number of alternatives is finite. For example, in deciding where to locate a new retail store in a certain part of the city, a manager could theoretically consider every grid coordinate on the city's map. Realistically, however, the manager must narrow the number of choices to a reasonable number.
2. List the *events* (sometimes called *chance events* or *states of nature*) that have an impact on the outcome of the choice but are not under the manager's control. For example, the demand experienced by the new facility could be low or high, depending not only on whether the location is convenient to many customers but also on what the competition does and general retail trends. Then, group events into reasonable categories. For example, suppose that the average number of sales per day could be anywhere from 1 to 500. Rather than have 500 events, the manager could represent demand with just three events: 100 sales/day, 300 sales/day, or 500 sales/day. The events must be mutually exclusive and collectively exhaustive, meaning that they do not overlap and that they cover all eventualities.
3. Calculate the *payoff* for each alternative in each event. Typically, the payoff is total profit or total cost. These payoffs can be entered into a **payoff table**, which shows the amount for each alternative if each possible event occurs. For three alternatives and four events, the table would have 12 payoffs (3×4). If significant distortions will occur if the time value of money is not recognized, the payoffs should be expressed as present values or internal rates of return (see MyOMLab Supplement F.) For multiple criteria with important qualitative factors, use the weighted scores of a preference matrix approach as the payoffs.
4. Estimate the likelihood of each event, using past data, executive opinion, or other forecasting methods. Express it as a *probability*, making sure that the probabilities sum to 1.0. Develop probability estimates from past data if the past is considered a good indicator of the future.
5. Select a *decision rule* to evaluate the alternatives, such as choosing the alternative with the lowest expected cost. The rule chosen depends on the amount of information the manager has on the event probabilities and the manager's attitudes toward risk.

payoff table

A table that shows the amount for each alternative if each possible event occurs.

MyOMLab

Using this process, we examine decisions under three different situations: certainty, uncertainty, and risk.

Decision Making under Certainty

The simplest situation is when the manager knows which event will occur. Here the decision rule is to pick the alternative with the best payoff for the known event. The best alternative is the highest payoff if the payoffs are expressed as profits. If the payoffs are expressed as costs, the best alternative is the lowest payoff.

EXAMPLE A.5 Decisions under Certainty

A manager is deciding whether to build a small or a large facility. Much depends on the future demand that the facility must serve, and demand may be small or large. The manager knows with certainty the payoffs that will result under each alternative, shown in the following payoff table. The payoffs (in $000) are the present values of future revenues minus costs for each alternative in each event.

	POSSIBLE FUTURE DEMAND	
Alternative	**Low**	**High**
Small facility	200	270
Large facility	160	800
Do nothing	0	0

What is the best choice if future demand will be low?

SOLUTION

In this example, the best choice is the one with the highest payoff. If the manager knows that future demand will be low, the company should build a small facility and enjoy a payoff of $200,000. The larger facility has a payoff of only $160,000. The "do nothing" alternative is dominated by the other alternatives; that is, the outcome of one alternative is no better than the outcome of another alternative for each event. Because the "do nothing" alternative is dominated, the manager does not consider it further.

DECISION POINT

If management really knows future demand, it would build the small facility if demand will be low and the large facility if demand will be high. If demand is uncertain, it should consider other decision rules.

Decision Making under Uncertainty

Here, we assume that the manager can list the possible events but cannot estimate their probabilities. Perhaps, a lack of prior experience makes it difficult for the firm to estimate probabilities. In such a situation, the manager can use one of four decision rules:

1. ***Maximin.*** Choose the alternative that is the "best of the worst." This rule is for the *pessimist*, who anticipates the "worst case" for each alternative.
2. ***Maximax.*** Choose the alternative that is the "best of the best." This rule is for the *optimist* who has high expectations and prefers to "go for broke."
3. ***Laplace.*** Choose the alternative with the best *weighted payoff.* To find the weighted payoff, give equal importance (or, alternatively, equal probability) to each event. If there are n events, the importance (or probability) of each is $1/n$, so they add up to 1.0. This rule is for the *realist.*
4. ***Minimax Regret.*** Choose the alternative with the best "worst regret." Calculate a table of regrets (or opportunity losses), in which the rows represent the alternatives and the columns represent the events. A regret is the difference between a given payoff and the best payoff in the same column. For an event, it shows how much is lost by picking an alternative to the one that is best for this event. The regret can be lost profit or increased cost, depending on the situation.

EXAMPLE A.6

Decisions under Uncertainty

MyOMLab

Tutor A.4 in MyOMLab provides a new example to make decisions under uncertainty.

Reconsider the payoff matrix in Example A.5. What is the best alternative for each decision rule?

SOLUTION

a. *Maximin.* An alternative's worst payoff is the *lowest* number in its row of the payoff matrix because the payoffs are profits. The worst payoffs ($000) are

Alternative	Worst Payoff
Small facility	200
Large facility	160

The best of these worst numbers is $200,000, so the pessimist would build a small facility.

b. *Maximax.* An alternative's best payoff ($000) is the *highest* number in its row of the payoff matrix, or

Alternative	Best Payoff
Small facility	270
Large facility	800

The best of these best numbers is $800,000, so the optimist would build a large facility.

c. *Laplace.* With two events, we assign each a probability of 0.5. Thus, the weighted payoffs ($000) are

Alternative	Weighted Payoff
Small facility	$0.5(200) + 0.5(270) =$ **235**
Large facility	$0.5(160) + 0.5(800) =$ **480**

The best of these weighted payoffs is $480,000, so the realist would build a large facility.

d. *Minimax Regret.* If demand turns out to be low, the best alternative is a small facility and its regret is 0 (or $200 - 200$). If a large facility is built when demand turns out to be low, the regret is 40 (or $200 - 160$).

	REGRET		
Alternative	**Low Demand**	**High Demand**	**Maximum Regret**
Small facility	$200 - 200 =$ **0**	$800 - 270 =$ **530**	**530**
Large facility	$200 - 160 =$ **40**	$800 - 800 =$ **0**	**40**

The column on the right shows the worst regret for each alternative. To minimize the maximum regret, pick a large facility. The biggest regret is associated with having only a small facility and high demand.

DECISION POINT

The pessimist would choose the small facility. The realist, optimist, and manager choosing to minimize the maximum regret would build the large facility.

Decision Making under Risk

Here we assume that the manager can list the events and estimate their probabilities. The manager has less information than with decision making under certainty, but more information than with decision making under uncertainty. For this intermediate situation, the *expected value* decision rule is widely used (both in practice and in this book). The expected value for an alternative is found by weighting each payoff with its associated probability and then adding the weighted payoff scores. The alternative with the best expected value (highest for profits and lowest for costs) is chosen.

This rule is much like the Laplace decision rule, except that the events are no longer assumed to be equally likely (or equally important). The expected value is what the *average* payoff would be if the decision could be repeated time after time. Of course, the expected value decision rule can result in a bad outcome if the wrong event occurs. However, it gives the best results if applied consistently over a long period of time. The rule should not be used if the manager is inclined to avoid risk.

EXAMPLE A.7 **Decisions under Risk**

Reconsider the payoff matrix in Example A.5. For the expected value decision rule, which is the best alternative if the probability of small demand is estimated to be 0.4 and the probability of large demand is estimated to be 0.6?

MyOMLab
Tutor A.5 in MyOMLab provides a new example to make decisions under risk.

SOLUTION

The expected value for each alternative is as follows:

Alternative	Expected Value
Small facility	$0.4(200) + 0.6(270) =$ **242**
Large facility	$0.4(160) + 0.6(800) =$ **544**

DECISION POINT

Management would choose a large facility if it used this expected value decision rule because it provides the best long-term results if consistently applied over time.

Decision Trees

The decision tree method is a general approach to a wide range of processes and supply chain decisions, such as product planning, process analysis, process capacity, and location. It is particularly valuable for evaluating different capacity expansion alternatives when demand is uncertain and sequential decisions are involved. For example, a company may expand a facility in 2015 only to discover in 2018 that demand is much higher than forecasted. In that case, a second decision may be necessary to determine whether to expand again or build a second facility.

A **decision tree** is a schematic model of alternatives available to the decision maker along with their possible consequences. The name derives from the tree-like appearance of the model. It consists of a number of square *nodes*, representing decision points, which are left by *branches* (which should be read from left to right), representing the alternatives. Branches leaving circular, or chance, nodes represent the events. The probability of each chance event, *P(E)*, is shown above each branch. The probabilities for all branches leaving a chance node must sum to 1.0. The conditional payoff, which is the payoff for each possible alternative–event combination, is shown at the end of each combination. Payoffs are given only at the outset, before the analysis begins, for the end points of each alternative–event combination. In Figure A.4, for example, payoff 1 is the financial outcome the manager expects if alternative 1 is chosen and then chance event 1 occurs.

decision tree
A schematic model of alternatives available to the decision maker, along with their possible consequences.

No payoff can be associated yet with any branches farther to the left, such as alternative 1 as a whole because it is followed by a chance event and is not an end point. Payoffs often are expressed as the present value of net profits. If revenues are not affected by the decision, the payoff is expressed as net costs.

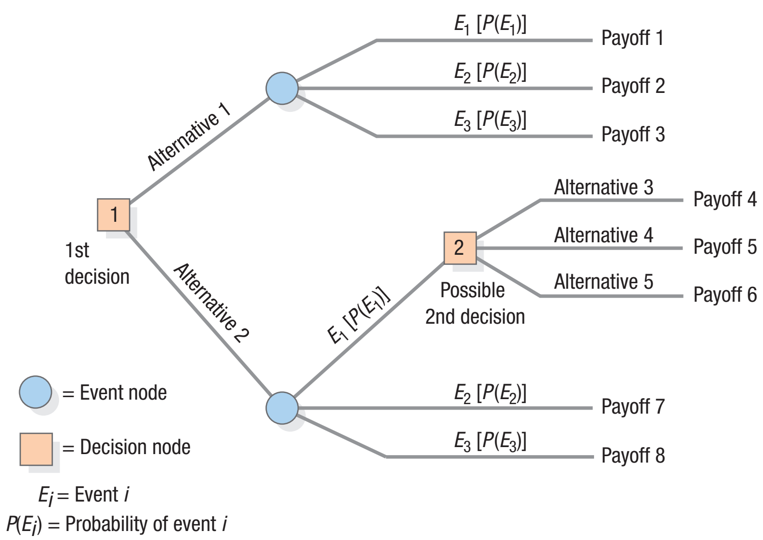


FIGURE A.4
A Decision Tree Model

After drawing a decision tree, we solve it by working from right to left, calculating the *expected payoff* for each node as follows:

1. For an event node, we multiply the payoff of each event branch by the event's probability. We add these products to get the event node's expected payoff.
2. For a decision node, we pick the alternative that has the best expected payoff. If an alternative leads to an event node, its payoff is equal to that node's expected payoff (already calculated). We "saw off," or "prune," the other branches not chosen by marking two short lines through them. The decision node's expected payoff is the one associated with the single remaining unpruned branch. We continue this process until the leftmost decision node is reached. The unpruned branch extending from it is the best alternative to pursue. If multistage decisions are involved, we must await subsequent events before deciding what to do next. If new probability or payoff estimates are obtained, we repeat the process.

Various software applications are available for drawing decision trees. PowerPoint can be used to draw decision trees, although it does not have the capability to analyze the decision tree. More extensive capabilities, in addition to POM for Windows, are found with SmartDraw (**http://www.smartdraw.com**), PrecisionTree decision analysis from Palisade Corporation (**http://www.palisade.com**), and TreePlan (**http://www.treeplan.com/treeplan.htm**).

EXAMPLE A.8 Analyzing a Decision Tree

MyOMLab

Active Model A.3 in MyOMLab provides additional insight on this decision tree example and its extensions.

A retailer must decide whether to build a small or a large facility at a new location. Demand at the location can be either low or high, with probabilities estimated to be 0.4 and 0.6, respectively. If a small facility is built and demand proves to be high, the manager may choose not to expand (payoff = \$223,000) or to expand (payoff = \$270,000). If a small facility is built and demand is low, there is no reason to expand and the payoff is \$200,000. If a large facility is built and demand proves to be low, the choice is to do nothing (\$40,000) or to stimulate demand through local advertising. The response to advertising may be either modest or sizable, with their probabilities estimated to be 0.3 and 0.7, respectively. If it is modest, the payoff is estimated to be only \$20,000; the payoff grows to \$220,000 if the response is sizable. Finally, if a large facility is built and demand turns out to be high, the payoff is \$800,000.

Draw a decision tree. Then analyze it to determine the expected payoff for each decision and event node. Which alternative—building a small facility or building a large facility—has the higher expected payoff?

SOLUTION

The decision tree in Figure A.5 shows the event probability and the payoff for each of the seven alternative-event combinations. The first decision is whether to build a small or a large facility. Its node is shown first, to the left, because it is the decision the retailer must make now. The second decision node—whether to expand at a later date—is reached only if a small facility is built and demand turns out to be high. Finally, the third decision point—whether to advertise—is reached only if the retailer builds a large facility and demand turns out to be low.

Analysis of the decision tree begins with calculation of the expected payoffs from right to left, shown on Figure A.5 beneath the appropriate event and decision nodes.

1. For the event node dealing with advertising, the expected payoff is 160, or the sum of each event's payoff weighted by its probability $[0.3(20) + 0.7(220)]$.
2. The expected payoff for decision node 3 is 160 because *Advertise* (160) is better than *Do nothing* (40). Prune the *Do nothing* alternative.
3. The payoff for decision node 2 is 270 because *Expand* (270) is better than *Do not expand* (223). Prune *Do not expand*.
4. The expected payoff for the event node dealing with demand, assuming that a small facility is built, is 242 $[\text{or } 0.4(200) + 0.6(270)]$.
5. The expected payoff for the event node dealing with demand, assuming that a large facility is built, is 544 $[\text{or } 0.4(160) + 0.6(800)]$.
6. The expected payoff for decision node 1 is 544 because the large facility's expected payoff is largest. Prune *Small facility*.

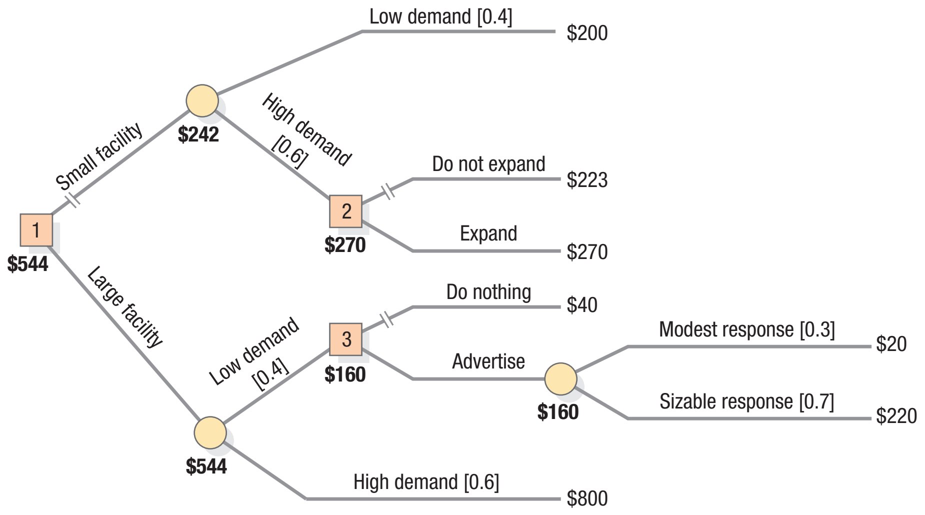


FIGURE A.5
Decision Tree for Retailer (in $000)

MyOMLab Animation

DECISION POINT

The retailer should build the large facility. This initial decision is the only one made now. Subsequent decisions are made after learning whether demand actually is low or high.

LEARNING GOALS IN REVIEW

Learning Goal	Guidelines for Review	MyOMLab Resources
1 Explain break-even analysis using both the graphic and algebraic approaches.	The section "Break-Even Analysis," pp. 49–53, covers this analysis. Example A.1 and Solved Problem 1 demonstrate both approaches. Example A.3 shows its use in evaluating different processes.	**Active Model Exercises:** A.1: Break-Even Analysis; A.2: Make-or-Buy Decision **OM Explorer Solver:** Break-Even Analysis **OM Explorer Tutors:** A.1: Break-Even Analysis; Evaluating Services and Products; A.2: Break-Even Analysis; Evaluating Processes **POM for Windows:** Break-Even Analysis; Cost-Volume Analysis
2 Define and construct a preference matrix.	See the section "Preference Matrix," pp. 53–54, for making decisions involving unquantifiable factors, where some factors are rated more important than others. Example A.4 and Solved Problem 2 demonstrate the calculations.	**OM Explorer Solver:** Preference Matrix **OM Explorer Tutor:** A3: Preference Matrix **POM for Windows:** Preference Matrix
3 Explain how decision theory can be used to make decisions under conditions of certainty, uncertainty, and risk.	The section "Decision Theory," pp. 54–57, begins with the construction of a payoff table that shows the payoff for each feasible alternative and each event. See the table in Example A.5. In addition, the sections "Decision Making under Uncertainty" and "Decision Making under Risk," pp. 56–57, cover these decision rules for when the outcomes associated with alternatives are in doubt. Examples A.6 and A.7 demonstrate how these rules work and so does Solved Problem 3.	**OM Explorer Solver:** Decision Theory **OM Explorer Tutors:** A.4: Decisions under Uncertainty; A.5: Decisions under Risk; A.6: Location Decisions under Uncertainty **POM for Windows:** Decision Tables
4 Describe how to draw and analyze a decision tree.	The section "Decision Trees," pp. 57–59, shows how to draw and analyze decision trees where several alternatives are available over time. Example A.8 and Solved Problem 4 shows how to work back from right to left, pruning as you go, until the best alternative is found for decision node 1.	**Active Model Exercise:** A.3: Decision Tree **POM for Windows:** Decision Trees (graphical)

Key Equations

Break-Even Analysis

1. Break-even quantity: $Q = \dfrac{F}{p - c}$

2. Evaluating processes, make-or-buy indifference quantity: $Q = \dfrac{F_m - F_b}{c_b - c_m}$

Key Terms

break-even analysis 49
break-even quantity 49
decision theory 54
decision tree 57
fixed cost 50
payoff table 54
preference matrix 53
sensitivity analysis 51
variable cost 50

Solved Problem 1

The owner of a small manufacturing business has patented a new device for washing dishes and cleaning dirty kitchen sinks. Before trying to commercialize the device and add it to his or her existing product line, the owner wants reasonable assurance of success. Variable costs are estimated at $7 per unit produced and sold. Fixed costs are about $56,000 per year.

a. If the selling price is set at $25, how many units must be produced and sold to break even? Use both algebraic and graphic approaches.

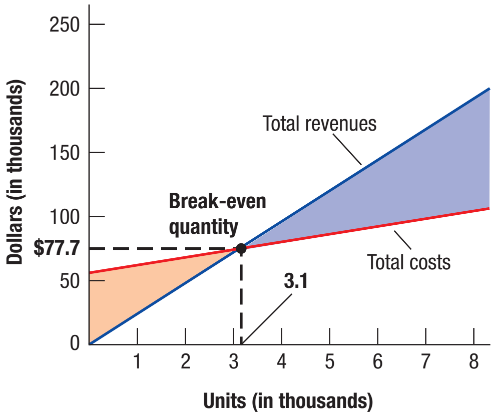
b. Forecasted sales for the first year are 10,000 units if the price is reduced to $15. With this pricing strategy, what would be the product's total contribution to profits in the first year?

SOLUTION

a. Beginning with the algebraic approach, we get

$$Q = \frac{F}{p - c} = \frac{56,000}{25 - 7}$$
$$= \mathbf{3,111} \text{ units}$$

FIGURE A.6 ▶



Using the graphic approach, shown in Figure A.6, we first draw two lines:

$$\text{Total revenue} = 25Q$$
$$\text{Total cost} = 56{,}000 + 7Q$$

The two lines intersect at $Q = 3{,}111$ units, the break-even quantity.

b. Total profit contribution $=$ Total revenue $-$ Total cost

$$= pQ - (F + cQ)$$
$$= 15(10{,}000) - [56{,}000 + 7(10{,}000)]$$
$$= \mathbf{\$24{,}000}$$

Solved Problem 2

MyOMLab Video

Herron Company is screening three new product ideas: A, B, and C. Resource constraints allow only one of them to be commercialized. The performance criteria and ratings, on a scale of 1 (worst) to 10 (best), are shown in the following table. The Herron managers give equal weights to the performance criteria. Which is the best alternative, as indicated by the preference matrix method?

	RATING		
Performance Criterion	**Product A**	**Product B**	**Product C**
1. Demand uncertainty and project risk	3	9	2
2. Similarity to present products	7	8	6
3. Expected return on investment (ROI)	10	4	8
4. Compatibility with current manufacturing process	4	7	6
5. Competitive advantage	4	6	5

SOLUTION

Each of the five criteria receives a weight of 1/5 or 0.20.

Product	Calculation	Total Score
A	$(0.20 \times 3) + (0.20 \times 7) + (0.20 \times 10) + (0.20 \times 4) + (0.20 \times 4)$	= 5.6
B	$(0 \times 9) + (0.20 \times 8) + (0.20 \times 4) + (0.20 \times 7) + (0.20 \times 6)$	= **6.8**
C	$(0.20 \times 2) + (0.20 \times 6) + (0.20 \times 8) + (0.20 \times 6) + (0.20 \times 5)$	= 5.4

The best choice is Product B. Products A and C are well behind in terms of total weighted score.

Solved Problem 3

MyOMLab

Tutor A.6 in MyOMLab examines decisions under uncertainty for a location example.

Adele Weiss manages the campus flower shop. Flowers must be ordered three days in advance from her supplier in Mexico. Although Valentine's Day is fast approaching, sales are almost entirely last-minute, impulse purchases. Advance sales are so small that Weiss has no way to estimate the probability of low (25 dozen), medium (60 dozen), or high (130 dozen) demand for red roses on the big day. She buys roses for $15 per dozen and sells them for $40 per dozen. Construct a payoff table. Which decision is indicated by each of the following decision criteria?

a. Maximin

b. Maximax

c. Laplace

d. Minimax regret

SOLUTION

The payoff table for this problem is

	DEMAND FOR RED ROSES		
Alternative	**Low (25 dozen)**	**Medium (60 dozen)**	**High (130 dozen)**
Order 25 dozen	$625	$625	$625
Order 60 dozen	$100	$1,500	$1,500
Order 130 dozen	($950)	$450	$3,250
Do nothing	$0	$0	$0

a. Under the maximin criteria, Weiss should order **25** dozen, because if demand is low, Weiss's profits are $625, the best of the worst payoffs.

b. Under the maximax criteria, Weiss should order **130** dozen. The greatest possible payoff, $3,250, is associated with the largest order.

c. Under the Laplace criteria, Weiss should order **60** dozen. Equally weighted payoffs for ordering 25, 60, and 130 dozen are about \$625, \$1,033, and \$917, respectively.

d. Under the minimax regret criteria, Weiss should order **130** dozen. The maximum regret of ordering 25 dozen occurs if demand is high: \$3,250 − \$625 = \$2,625. The maximum regret of ordering 60 dozen occurs if demand is high: \$3,250 − \$1,500 = \$1,750. The maximum regret of ordering 130 dozen occurs if demand is low: \$625 − (−\$950) = **\$1,575**.

Solved Problem 4

White Valley Ski Resort is planning the ski lift operation for its new ski resort. Management is trying to determine whether one or two lifts will be necessary; each lift can accommodate 250 people per day. Skiing normally occurs in the 14-week period from December to April, during which the lift will operate seven days per week. The first lift will operate at 90 percent capacity if economic conditions are bad, the probability of which is believed to be about a 0.3. During normal times the first lift will be utilized at 100 percent capacity, and the excess crowd will provide 50 percent utilization of the second lift. The probability of normal times is 0.5. Finally, if times are really good, the probability of which is 0.2, the utilization of the second lift will increase to 90 percent. The equivalent annual cost of installing a new lift, recognizing the time value of money and the lift's economic life, is \$50,000. The annual cost of installing two lifts is only \$90,000 if both are purchased at the same time. If used at all, each lift costs \$200,000 to operate, no matter how low or high its utilization rate. Lift tickets cost \$20 per customer per day.

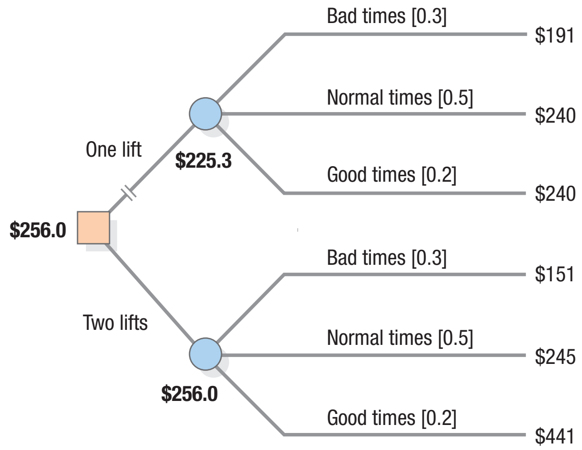
Should the resort purchase one lift or two?

SOLUTION

The decision tree is shown in Figure A.7. The payoff (\$000) for each alternative-event branch is shown in the following table. The total revenues from one lift operating at 100 percent capacity are **\$490,000** (or 250 customers × 98 days × \$20/customer-day).

Alternative	Economic Condition	Payoff Calculation (Revenue – Cost)
One lift	Bad times	$0.9(490) - (50 + 200) = 191$
	Normal times	$1.0(490) - (50 + 200) = 240$
	Good times	$1.0(490) - (50 + 200) = 240$
Two lifts	Bad times	$0.9(490) - (90 + 200) = 151$
	Normal times	$1.5(490) - (90 + 400) = 245$
	Good times	$1.9(490) - (90 + 400) = 441$

FIGURE A.7 ▶



Problems

The OM Explorer and POM for Windows software is available to all students using the 11th edition of this textbook. Go to **http://www.pearsonglobaleditions.com/Krajewski** to download these computer packages. If you purchased MyOMLab, you also have access to Active Models software and significant help in doing the following problems. Check with your instructor on how best to use these resources. In many cases, the instructor wants you to understand how to do the calculations by hand. At the least, the software provides a check on your calculations. When calculations are particularly complex and the goal is interpreting the results in making decisions, the software entirely replaces the manual calculations.

Break-Even Analysis

1. Mary Williams, owner of Williams Products, is evaluating whether to introduce a new product line. After thinking through the production process and the costs of raw materials and new equipment, Williams estimates the variable costs of each unit produced and sold at $6 and the fixed costs per year at $60,000.

a. If the selling price is set at $18 each, how many units must be produced and sold for Williams to break even? Use both graphic and algebraic approaches to get your answer.

b. Williams forecasts sales of 10,000 units for the first year if the selling price is set at $14 each. What would be the total contribution to profits from this new product during the first year?

c. If the selling price is set at $12.50, Williams forecasts that first-year sales would increase to 15,000 units. Which pricing strategy ($14.00 or $12.50) would result in the greater total contribution to profits?

d. What other considerations would be crucial to the final decision about making and marketing the new product?

2. A product at the Jennings Company enjoyed reasonable sales volumes, but its contributions to profits were disappointing. Last year, 17,500 units were produced and sold. The selling price is $22 per unit, the variable cost is $18 per unit, and the fixed cost is $80,000.

a. What is the break-even quantity for this product? Use both graphic and algebraic approaches to get your answer.

b. If sales were not expected to increase, by how much would Jennings have to reduce their variable cost to break even?

c. Jennings believes that a $1 reduction in price will increase sales by 50 percent. Is this enough for Jennings to break even? If not, by how much would sales have to increase?

d. Jennings is considering ways to either stimulate sales volume or decrease variable cost. Management believes that either sales can be increased by 30 percent or that variable cost can be reduced to 85 percent of its current level. Which alternative leads to higher contributions to profits, assuming that each is equally costly to implement? (*Hint:* Calculate profits for both alternatives and identify the one having the greatest profits.)

e. What is the percent change in the per-unit profit contribution generated by each alternative in part (d)?

3. An interactive television service that costs $10 per *month* to provide can be sold on the information highway for $15 per client per *month*. If a service area includes a potential of 15,000 customers, what is the most a company could spend on *annual* fixed costs to acquire and maintain the equipment?

4. A restaurant is considering adding fresh brook trout to its menu. Customers would have the choice of catching their own trout from a simulated mountain stream or simply asking the waiter to net the trout for them. Operating the stream would require $10,600 in fixed costs per year. Variable costs are estimated to be $6.70 per trout. The firm wants to break even if 800 trout dinners are sold per year. What should be the price of the new item?

5. Spartan Castings must implement a manufacturing process that reduces the amount of particulates emitted into the atmosphere. Two processes have been identified that provide the same level of particulate reduction. The first process is expected to incur $350,000 of fixed cost and add $50 of variable cost to each casting Spartan produces. The second process has fixed costs of $150,000 and adds $90 of variable cost per casting.

a. What is the break-even quantity beyond which the first process is more attractive?

b. What is the difference in total cost if the quantity produced is 10,000?

6. A news clipping service is considering modernization. Rather than manually clipping and photocopying articles of interest and mailing them to its clients, employees electronically input stories from most widely circulated publications into a database. Each new issue is searched for key words, such as a client's company name, competitors' names, type of business, and the company's products, services, and officers. When matches occur, affected clients are instantly notified via an online network. If the story is of interest, it is electronically transmitted, so the client often has the story and can prepare comments for follow-up interviews before the publication hits the street. The manual process has fixed costs of $400,000 per year and variable costs of $6.20 per clipping mailed. The price charged the client is $8.00 per clipping. The computerized process has fixed costs of $1,300,000 per year and variable costs of $2.25 per story electronically transmitted to the client.

a. If the same price is charged for either process, what is the annual volume beyond which the automated process is more attractive?

b. The present volume of business is 225,000 clippings per year. Many of the clippings sent with the current process are not of interest to the client or are multiple copies of the same story appearing in several publications. The news clipping service believes that by improving service and by lowering the price to $4.00 per story, modernization will increase volume to 900,000 stories transmitted per year. Should the clipping service modernize?

c. If the forecasted increase in business is too optimistic, at what volume will the new process (with the $4.00 price) break even?

7. Hahn Manufacturing purchases a key component of one of its products from a local supplier. The current purchase price is $1,500 per unit. Efforts to standardize parts succeeded to the point that this same component can now be used in five different products. Annual component usage should increase from 150 to 750 units. Management wonders whether it is time to make the component in-house rather than to continue buying it from the supplier. Fixed costs would increase by about $40,000 per year for the new equipment and tooling needed. The cost of raw materials and variable overhead would be about $1,100 per unit, and labor costs would be $300 per unit produced.
   a. Should Hahn make rather than buy?
   b. What is the break-even quantity?
   c. What other considerations might be important?

8. Techno Corporation is currently manufacturing an item at variable costs of $5 per unit. Annual fixed costs of manufacturing this item are $140,000. The current selling price of the item is $10 per unit, and the annual sales volume is 30,000 units.
   a. Techno can substantially improve the item's quality by installing new equipment at additional annual fixed costs of $60,000. Variable costs per unit would increase by $1, but, as more of the better-quality product could be sold, the annual volume would increase to 50,000 units. Should Techno buy the new equipment and maintain the current price of the item? Why or why not?
   b. Alternatively, Techno could increase the selling price to $11 per unit. However, the annual sales volume would be limited to 45,000 units. Should Techno buy the new equipment and raise the price of the item? Why or why not?

9. The Tri-County Generation and Transmission Association is a nonprofit cooperative organization that provides electrical service to rural customers. Based on a faulty long-range demand forecast, Tri-County overbuilt its generation and distribution system. Tri-County now has much more capacity than it needs to serve its customers. Fixed costs, mostly debt service on investment in plant and equipment, are $82.5 million per year. Variable costs, mostly fossil fuel costs, are $25 per megawatt-hour (MWh, or million watts of power used for one hour). The new person in charge of demand forecasting prepared a short-range forecast for use in next year's budgeting process. That forecast calls for Tri-County customers to consume 1 million MWh of energy next year.
   a. How much will Tri-County need to charge its customers per MWh to break even next year?
   b. The Tri-County customers balk at that price and conserve electrical energy. Only 95 percent of forecasted demand materializes. What is the resulting surplus or loss for this nonprofit organization?

10. Earthquake, drought, fire, economic famine, flood, and a pestilence of TV court reporters have caused an exodus from the City of Angels to Boulder, Colorado. The sudden increase in demand is straining the capacity of Boulder's electrical system. Boulder's alternatives have been reduced to buying 150,000 MWh of electric power from Tri-County G&T at a price of $75 per MWh, or refurbishing and recommissioning the abandoned Pearl Street Power Station in downtown Boulder. Fixed costs of that project are $10 million per year, and variable costs would be $35 per MWh. Should Boulder build or buy?

11. Tri-County G&T sells 150,000 MWh per year of electrical power to Boulder at $75 per MWh, has fixed costs of $82.5 million per year, and has variable costs of $25 per MWh. If Tri-County has 1,000,000 MWh of demand from its customers (other than Boulder), what will Tri-County have to charge to break even?

Preference Matrix

12. The Forsite Company is screening three ideas for new services. Resource constraints allow only one idea to be commercialized at the present time. The following estimates have been made for the five performance criteria that management believes to be most important:

	RATING		
Performance Criterion	Service A	Service B	Service C
Capital equipment investment required	0.6	0.8	0.3
Expected return on investment (ROI)	0.7	0.3	0.9
Compatibility with current workforce skills	0.4	0.7	0.5
Competitive advantage	1.0	0.4	0.6
Compatibility with EPA requirements	0.2	1.0	0.5

   a. Calculate a total weighted score for each alternative. Use a preference matrix and assume equal weights for each performance criterion. Which alternative is best? Worst?
   b. Suppose that the expected ROI is given twice the weight assigned to each of the remaining criteria. (The sum of weights should remain the same as in part (a).) Does this modification affect the ranking of the three potential services?

13. You are in charge of analyzing five new suppliers of an important raw material and have been given the information shown below (1 = worst, 10 = best). Management has decided that criteria 2 and 3 are equally important and that criteria 1 and 4 are each four times as important as criterion 2. No more than two new suppliers are required but each new vendor must exceed a total score of 70 percent of the maximum total points to be considered.

	RATING				
Performance Criterion	Vendor A	Vendor B	Vendor C	Vendor D	Vendor E
Quality of raw material	8	7	3	6	9
Environmental impact	3	8	4	7	7
Responsiveness to order changes	9	5	7	6	5
Cost of raw material	7	6	9	2	7

a. Which new vendors do you recommend?

b. Would your decision change if the criteria were considered equally important?

14. Accel Express, Inc., collected the following information on where to locate a warehouse (1 = poor, 10 = excellent):

		LOCATION SCORE	
Location Factor	Factor Weight	A	B
Construction costs	10	8	5
Utilities available	10	7	7
Business services	10	4	7
Real estate cost	20	7	4
Quality of life	20	4	8
Transportation	30	7	6

a. Which location, A or B, should be chosen on the basis of the total weighted score?

b. If the factors were weighted equally, would the choice change?

15. Janice Gould of Krebs Consulting is in the process of making a recommendation to a client regarding the corporate-wide purchase of an analytical software platform. She has made the following estimates on management's most important performance criteria and has rated three Software packages across these criteria.

		RATING		
Performance Criterion	Factor Weight	Software A	Software B	Software C
Functionality	25	9	8	9
Vendor reliability	10	7	5	9
Compatibility with current systems	20	6	8	6
Maintenance & support	10	5	5	8
Total cost	25	4	8	5
Speed of implementation	10	8	4	7

a. Which software platform would you recommend?

b. Assume that the client changes their mind and now argues that the maintenance and support criterion is already accounted for by the total cost criterion. Further, the client asks Ms. Gould to drop maintenance and support and add its factor weight to total cost. Will this client request alter the recommendation?

Decision Theory

16. Build-Rite Construction has received favorable publicity from guest appearances on a public TV home improvement program. Public TV programming decisions seem to be unpredictable, so Build-Rite cannot estimate the probability of continued benefits from its relationship with the show. Demand for home improvements next year may be either low or high. But Build-Rite must decide now whether to hire more employees, do nothing, or develop subcontracts with other home improvement contractors. Build-Rite has developed the following payoff table:

	DEMAND FOR HOME IMPROVEMENTS		
Alternative	Low	Moderate	High
Hire	($250,000)	$100,000	$625,000
Subcontract	$100,000	$150,000	$415,000
Do nothing	$50,000	$80,000	$300,000

Which alternative is best, according to each of the following decision criteria?

a. Maximin

b. Maximax

c. Laplace

d. Minimax regret

17. Robert Ragsdale is trying to decide if he should purchase repair and replacement insurance on a new laptop computer that he is planning to purchase. The policy costs $400.00 at the time of purchase, and over the next three years will replace the laptop if it is stolen or repair it if it is broken. The following table contains the total costs of this decision.

Alternative	Computer Is Stolen	Computer Breaks	Computer Neither Breaks Nor Is Stolen
Buy the Insurance	$2,900.00	$2,900.00	$2,900.00
Do Not Buy the Insurance	$5,000.00	$3,100.00	$2,500.00

Which alternative is best, according to each of the following decision criteria?

a. Maximin

b. Maximax

c. Laplace

d. Minimax regret

18. Benjamin Moses, chief engineer of Offshore Chemicals, Inc., must decide whether to build a new processing facility based on an experimental technology. If the new facility works, the company will realize a net profit of $20 million. If the new facility fails, the company will lose $10 million. Benjamin's best guess is that there is a 40 percent chance that the new facility will work.

What decision should Benjamin Moses make?

19. A manager is trying to decide whether to build a small, medium, or large facility. Demand can be low, average, or high, with the estimated probabilities being 0.25, 0.40, and 0.35, respectively.

A small facility is expected to earn an after-tax net present value of just $18,000 if demand is low. If demand is average, the small facility is expected to earn $75,000; it can be increased to medium size to earn a net present value of $60,000. If demand is high, the small facility is expected to earn $75,000 and can be expanded to medium size to earn $60,000 or to large size to earn $125,000.

A medium-sized facility is expected to lose an estimated $25,000 if demand is low and earn $140,000 if demand is average. If demand is high, the medium-sized facility is expected to earn a net present value of $150,000; it can be expanded to a large size for a net payoff of $145,000.

If a large facility is built and demand is high, earnings are expected to be $220,000. If demand is average for the large facility, the present value is expected to be $125,000; if demand is low, the facility is expected to lose $60,000.

Which alternative is best, according to each of the following decision criterion?

a. Maximin

b. Maximax

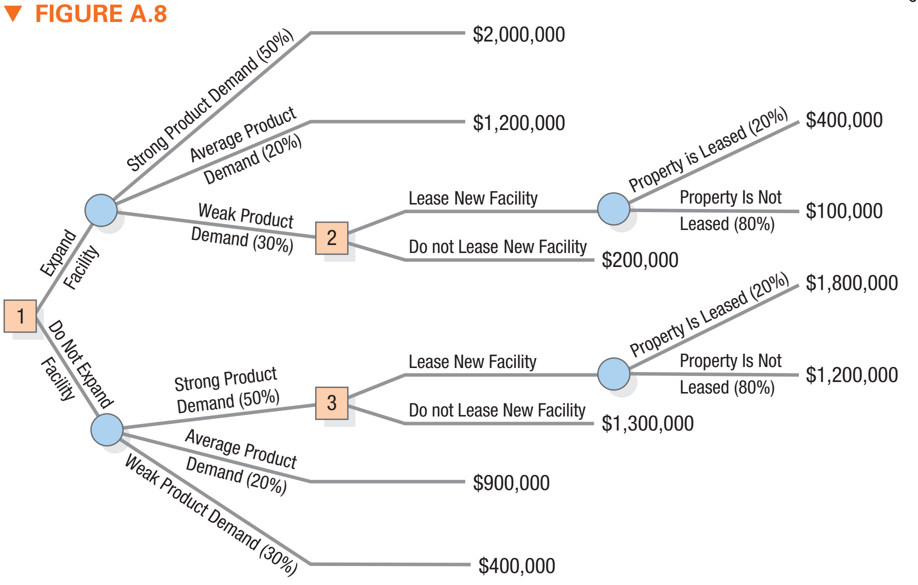
c. Minimax regret

Decision Trees

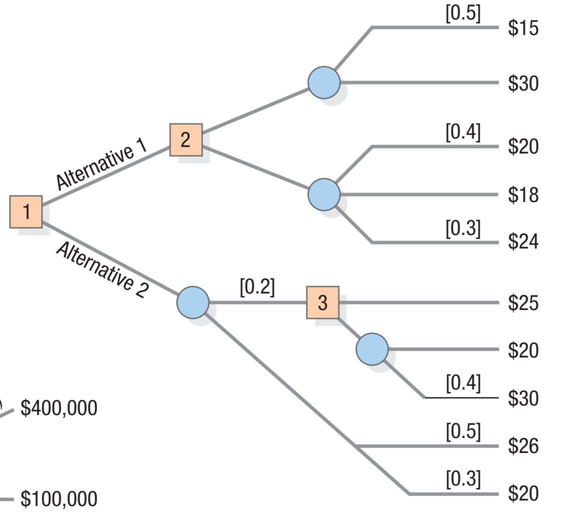
20. Draw a decision tree for the three options described in problem 19. What should management do to achieve the highest expected payoff?

21. The owner of Pearl Automotive Dealers is trying to decide whether to expand his current facility. If he expands and customer demand turns weak, there is a chance he could lease part of his newly constructed facility to another dealer. If he doesn't expand and strong demand occurs, he could attempt to lease another facility across town. Analyze the decision tree in Figure A8. What is the best set of decisions and the expected payoff?

▼ FIGURE A.8



22. Analyze the decision tree in the figure below. What is the expected payoff for the best alternative? First, be sure to infer the missing probabilities.



23. A manager is trying to decide whether to buy one machine or two. If only one is purchased and demand proves to be excessive, the second machine can be purchased later. Some sales will be lost, however, because the lead time for producing this type of machine is six months. In addition, the cost per machine will be lower if both are purchased at the same time. The probability of low demand is estimated to be 0.20. The after-tax net present value of the benefits from purchasing the two machines together is $90,000 if demand is low and $180,000 if demand is high.

If one machine is purchased and demand is low, the net present value is $120,000. If demand is high, the manager has three options. Doing nothing has a net present value of $120,000; subcontracting, $160,000; and buying the second machine, $140,000.

- **a.** Draw a decision tree for this problem.
- **b.** How many machines should the company buy initially? What is the expected payoff for this alternative?

24. A manufacturing plant has reached full capacity. The company must build a second plant—either small or large—at a nearby location. The demand is likely to be high or low. The probability of low demand is 0.3. If demand is low, the large plant has a present value of $5 million and the small plant, a present value of $8 million. If demand is high, the large plant pays off with a present value of $18 million, and the small plant with a present value of only $10 million. However, the small plant can be expanded later if demand proves to be high for a present value of $14 million.

- **a.** Draw a decision tree for this problem.
- **b.** What should management do to achieve the highest expected payoff?

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Rob Walls/Alamy

McDonald's continually seeks ways to re-design and improve its processes so as to provide better quality and menu choices to its customers at a lower cost, with more sustainable resources.

2

PROCESS STRATEGY AND ANALYSIS

McDonald's Corporation

As a global food service retailer, McDonald's has more than 35,000 restaurants around the world, and 70 million customers visit them each day. It employs 1.9 million people who work for McDonald's and its franchisees across more than 100 countries. Even though the company is a leader in its industry, things were not so good in 2002, when customer complaints were growing more frequent and bitter. McDonald's began listening to the customers again and changed its processes to reflect it. The board brought on a new CEO who had spent 20 years on the operational side of the business. With a zeal for measuring customer satisfaction and sharing the data freely with operators, he pulled off a turnaround that stunned everyone in the business with its speed and scope. Initiatives were launched to collect performance measures and revamp McDonald's processes to meet customer expectations. Data on speed of service; food temperature; presentation and taste; cleanliness of the counter, tables and condiment islands; even whether the counter crewperson smiles at diners, was collected using mystery shoppers. Operators could pinpoint lingering problems, and performance measures focused operators' attention on needed process changes. Customers were encouraged to report their experience at a particular U.S. restaurant by e-mail, regular mail, or toll-free telephone call.

Another initiative was to send 900 operations missionaries into the field, each visiting stores multiple times to fine-tune processes while also conducting day-long seminars where store managers could share tips from corporate kitchen gurus—such as where to place staff—that would shave precious seconds off average service times. The process was changed back to toasting buns rather than microwaving them, giving them an even sweeter caramelized flavor. Other initiatives were taken on McDonald's fast lane. Outdoor menu boards were placed with more pictures and fewer words. An LED display confirmed what customers ordered, reducing confusion later on. Premium sandwiches were put in boxes rather than paper wrappers, saving a few seconds, and boxes were color coded by sandwich to improve speed and accuracy. Processes were also changed to become environment friendly, all the way from the counters of McDonald's restaurants into its supply chain. All these changes resulted in greater profitability and share price over ten years, as performance measurement and process analysis increased customer value and the bottom line.

Lately, however, the growth has stagnated. Same-store sales slipped 0.1 percent, which marked a second quarterly decline in 2013. The menu got overly complicated as more items were added to suit a wider range of tastes. This created bottlenecks in the kitchen, which slowed service and turned off customers. Some items, like chicken wings, were too pricey for customers' taste and resulted in 10 million pounds of unsold wings. To regain focus, McDonalds is now redesigning its kitchens to include prep tables that would give employees more space for assembling food. In addition, $3 billion in capital expenditures is being budgeted in 2014 for opening new restaurants and refurbishing existing ones. Apart from making the menu more relevant to closely reflect customer preferences, more employees would also be hired at peak hours and weekends to increase speed of service.

Even at successful firms like McDonald's, it is easy to lose touch over time. Careful design and execution of processes that appropriately reflect product designs and market trends ultimately drive business outcomes and financial success.

Source: Julie Jargon, "McDonald's Says Its Restaurants Got Too Complicated," *Wall Street Journal*, January 24, 2014; Daniel Kruger, "You Want Data with That?" *Forbes*, vol. 173, no. 6 (March 2004), pp. 58–60; **http://www.mcdonalds.com**, June 26, 2014.

Using Operations to Create Value

PROCESS MANAGEMENT

→ **Process Strategy and Analysis**
Managing Quality
Planning Capacity
Managing Process Constraints
Designing Lean Systems
Managing Effective Projects

CUSTOMER DEMAND MANAGEMENT

Forecasting Demand
Managing Inventories
Planning and Scheduling Operations
Efficient Resource Planning

SUPPLY CHAIN MANAGEMENT

Designing Effective Supply Chains
Supply Chains and Logistics
Integrating the Supply Chain
Managing Supply Chain Sustainability

LEARNING GOALS *After reading this chapter, you should be able to:*

1. Understand the process structure in services and how to position a service process on the customer-contact matrix.
2. Understand the process structure in manufacturing and how to position a manufacturing process on the product-process matrix.
3. Explain the major process strategy decisions and their implications for operations.
4. Discuss how process decisions should strategically fit together.
5. Compare and contrast the two commonly used strategies for change, and understand a systematic way to analyze and improve processes.
6. Discuss how to document and evaluate processes.
7. Identify the commonly used approaches for effectively redesigning and managing processes.

Processes involve the use of an organization's resources to provide something of value and are perhaps the least understood and managed aspect of a business. No service can be provided and no product can be made without a process, and no process can exist without at least one service or product. Even with talented and motivated people, a firm cannot gain competitive advantage with faulty processes. Process decisions as such are strategic in nature. As we saw in Chapter 1, they should further a company's long-term competitive goals. In making process decisions, managers focus on controlling such competitive priorities as quality, flexibility, time, and cost. As exemplified by McDonald's, process management is an ongoing activity, with the same principles applying to both first-time and redesign choices. Many different choices are available in selecting human resources, equipment, outsourced services, materials, work flows, and methods that transform inputs into outputs. Another choice is which processes are to be done in-house and which processes are to be outsourced—that is, done outside the firm and purchased as materials and services. This decision helps to define the supply chain, and is covered more fully in subsequent chapters.

In this chapter, we focus on **process strategy**, which specifies the pattern of decisions made in managing processes so that the processes will achieve their competitive priorities, as well as **process analysis**, which is the documentation and detailed understanding of how work is performed and how it can be redesigned. Process decisions directly affect the process itself and indirectly the services and the products that it provides. All parts of an organization, as well as external suppliers and customers across the supply chain, need to be involved to ensure that processes are providing the most value to their internal and external customers.

Process strategy guides a variety of process decisions, and in turn is guided by operations strategy and the organization's ability to obtain the resources necessary to support them. We begin by defining four basic process decisions: (1) process structure, (2) customer involvement, (3) resource flexibility, and (4) capital intensity. We discuss these decisions for both service and manufacturing processes. We pay particular attention to ways in which these decisions fit together, depending on factors such as competitive priorities, customer contact, and volume, which in turn lead to two basic change strategies for analyzing and modifying processes: (1) process reengineering and (2) process improvement. Both these approaches need process analysis to identify and implement changes.

Three principles concerning process strategy are particularly important:

1. The key to successful process decisions is to make choices that fit the situation and that make sense together. They should not work at cross-purposes, with one process optimized at the expense of other processes. A more effective process is one that matches key process characteristics and has a close *strategic fit*.
2. Although this section of the text focuses on individual processes, they are the building blocks that eventually create the firm's whole supply chain. The cumulative effect on customer satisfaction and competitive advantage is huge.
3. Whether processes in the supply chain are performed internally or by outside suppliers and customers, management must pay particular attention to the interfaces between processes. Dealing with these interfaces underscores the need for cross-functional coordination.

Whether dealing with processes for offices, service providers, or manufacturers, operations managers must consider four common process decisions. Figure 2.1 shows that they are all important steps toward an effective process design. These four decisions are best understood at the process or subprocess level rather than at the firm level.

- **Process structure** determines the process type relative to the kinds of resources needed, how resources are partitioned between them, and their key characteristics. A **layout** is the physical arrangement of operations (or departments) relative to each other.
- **Customer involvement** reflects the ways in which customers become part of the process and the extent of their participation.
- **Resource flexibility** is the ease with which employees and equipment can handle a wide variety of products, output levels, duties, and functions.
- **Capital intensity** is the mix of equipment and human skills in a process. The greater the cost of equipment relative to the cost of labor, the greater is the capital intensity.

The concepts that we develop around these four decisions establish a framework within which we can address the appropriate process design in every situation. We establish the patterns of choices

process strategy

The pattern of decisions made in managing processes so that they will achieve their competitive priorities.

process analysis

The documentation and detailed understanding of how work is performed and how it can be redesigned.

process structure

The process type relative to the kinds of resources needed, how resources are partitioned between them, and their key characteristics.

layout

The physical arrangement of operations (or departments) relative to each other.

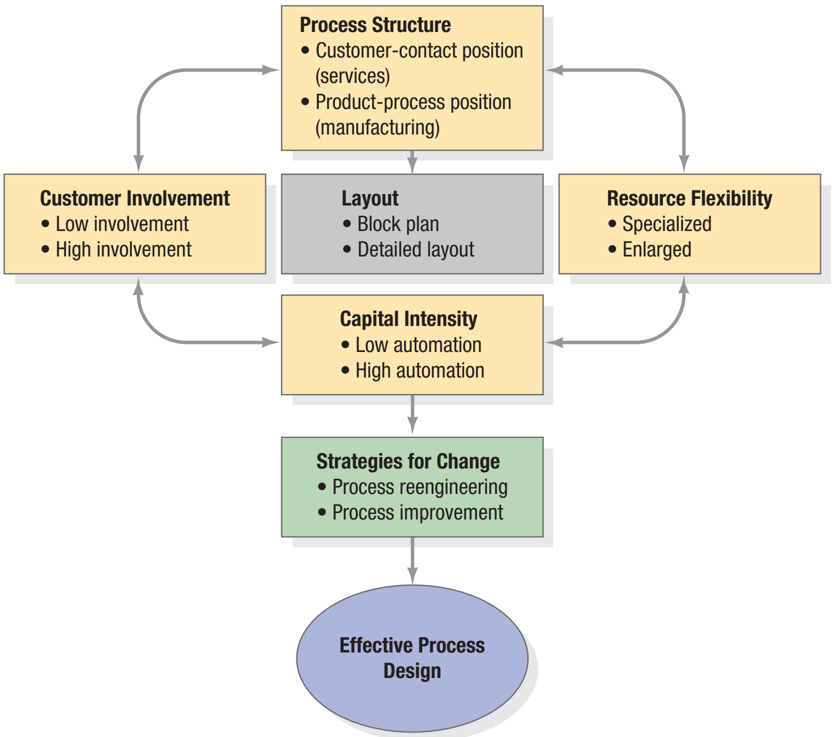
customer involvement

The ways in which customers become part of the process and the extent of their participation.

resource flexibility

The ease with which employees and equipment can handle a wide variety of products, output levels, duties, and functions.

FIGURE 2.1
Major Decisions for Effective Processes



capital intensity

The mix of equipment and human skills in a process.

that create a good fit between the four decisions. For example, if you walk through a manufacturing facility where materials flow smoothly from one work station to the next (which we will define later to be a *line* process), you would be tempted to conclude that all processes should be line processes. They seem so efficient and organized. However, converting to a line process would be a big mistake if volumes are low and the products made are customized. Resources must be more flexible to handle a variety of products in such a situation. The result is a more disorganized appearance with jobs crisscrossing in many different directions depending on the product being made. Despite appearances, this process is the best choice.

Process Structure in Services

One of the first decisions a manager makes in designing a well-functioning process is to choose a process type that best achieves the competitive priorities for that process. Strategies for designing processes can be quite different, depending on whether a service is being provided or a product is being manufactured. We begin with service processes, given their huge implication for workforce resources in industrialized countries.

customer contact

The extent to which the customer is present, is actively involved, and receives personal attention during the service process.

A process strategy that gets customers in and out of a fast-food restaurant quickly would not be the right process strategy for a five-star restaurant, where customers seek a leisurely dining experience. To gain insights, we must start at the process level and recognize key contextual variables associated with the process. A good process strategy for a service process depends first and foremost on the type and amount of customer contact. **Customer contact** is the extent to which the customer is present, is actively involved, and receives personal attention during the service process. Face-to-face interaction, sometimes called a *moment of truth* or *service encounter*, brings the customer and service providers together. At that time, customer attitudes about the quality of the service provided are shaped. Table 2.1 shows several dimensions of customer contact. Many levels are possible on each of the five dimensions. Also, some parts of a process can have low contact and other parts of a process can have high contact.

TABLE 2.1 DIMENSIONS OF CUSTOMER CONTACT IN SERVICE PROCESSES

Dimension	High Contact	Low Contact
Physical presence	Present	Absent
What is processed	People	Possessions or information
Contact intensity	Active, visible	Passive, out of sight
Personal attention	Personal	Impersonal
Method of delivery	Face-to-face	Regular mail or e-mail

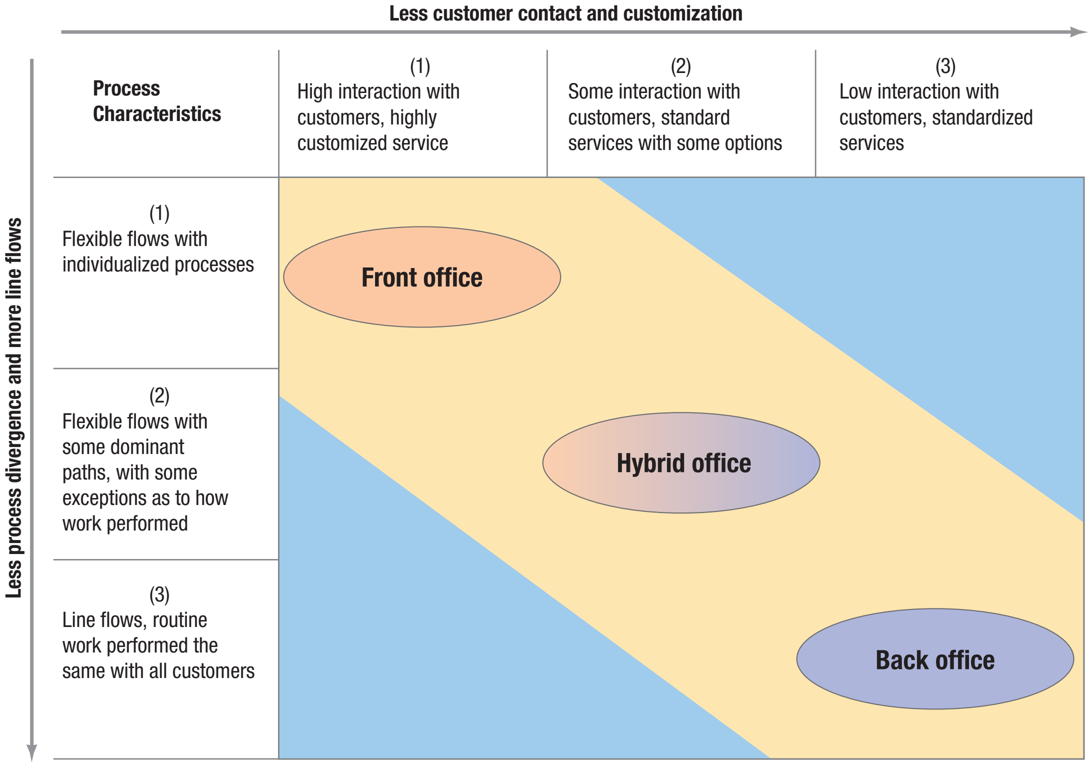
Customer-Contact Matrix

The customer-contact matrix, shown in Figure 2.2, brings together three elements: (1) the degree of customer contact, (2) customization, and (3) process characteristics. The matrix is the starting point for evaluating and improving a process.

FIGURE 2.2 ▶

Customer-Contact Matrix for Service Processes

MyOMLab Animation



Customer Contact and Customization The horizontal dimension of the matrix represents the service provided to the customer in terms of customer contact and competitive priorities. A key competitive priority is how much customization is needed. Positions on the left side of the matrix represent high customer contact and highly customized services. The customer is more likely to be present and active. The process is more likely to be visible to the customer, who receives more personal attention. The right side of the matrix represents low customer contact, passive involvement, less personalized attention, and a process out of the customer's sight.

Process Divergence and Flow The vertical dimension of the customer-contact matrix deals with two characteristics of the process itself: (1) process divergence and (2) flow. Each process can be analyzed on these two dimensions.

Process divergence is the extent to which the process is highly customized with considerable latitude as to how its tasks are performed. If the process changes with each customer, virtually every performance of the service is unique. Examples of highly divergent service processes where many steps in them change with each customer are found in consulting, law, and architecture. A service with low divergence, on the other hand, is repetitive and standardized. The work is performed exactly the same with all customers and tends to be less complex. Certain hotel services and telephone services are highly standardized to ensure uniformity.

Closely related to divergence is how the customer, object, or information being processed flows through the service facility. Work progresses through the sequence of steps in a process, which could range from highly diverse to linear. When divergence is considerable, the work flow tends to be more flexible. A **flexible flow** means that the customers, materials, or information move in diverse ways, with the path of one customer or job often crisscrossing the path that the next one takes. Each one can follow a carefully preplanned path, even though the first impression is one of disorganized, jumbled flows. Such an appearance goes naturally with high process divergence. A **line flow** means that the customers, materials, or information move linearly from one operation to the next, according to a fixed sequence. When diversity is low and the process standardized, line flows are a natural consequence.

process divergence

The extent to which the process is highly customized with considerable latitude as to how its tasks are performed.

flexible flow

The customers, materials, or information move in diverse ways, with the path of one customer or job often crisscrossing the path that the next one takes.

line flow

The customers, materials, or information move linearly from one operation to the next, according to a fixed sequence.

front office

A process with high customer contact where the service provider interacts directly with the internal or external customer.

hybrid office

A process with moderate levels of customer contact and standard services with some options available.

Service Process Structuring

Figure 2.2 shows several desirable positions in the matrix that effectively connect the service product with the process. The manager has three process structures, which form a continuum, to choose from: (1) front office, (2) hybrid office, and (3) back office. It is unlikely that a process can be a top performer if a process lies too far from one of these diagonal positions, occupying instead one of the extreme positions represented by the light blue triangles in the matrix (refer to Figure 2.2). Such positions represent too much of a disconnect between the service provided and process characteristics.

Front Office A **front-office** process has high customer contact where the service provider interacts directly with the internal or external customer. Because of the customization of the service and variety of service options, many of the steps in it have considerable divergence. Work flows are flexible, and they vary from one customer to the next. The high-contact service process tends to be adapted or tailored to each customer.

Hybrid Office A hybrid office tends to be in the middle of the five dimensions in Table 2.1, or perhaps high on some contact measures and low on others. A **hybrid-office** process has moderate levels of customer contact and standard services, with some options available from which the customer chooses. The work flow progresses from one workstation to the next, with some dominant paths apparent.

Monkey Business/Fotolia

A financial consultant discusses options with a couple at their home. This process scores high on customer contact, because the customers are present, take an active part in creating the service, receive personal attention, and have a face-to-face meeting.

back office
A process with low customer contact and little service customization.

Back Office A **back-office** process has low customer contact and little service customization. The work is standardized and routine, with line flows from one service provider to the next until the service is completed. Preparing the monthly client fund balance reports in the financial services industry is a good example. It has low customer contact, low divergence, and a line flow.

Serge Kozak/Corbis

Employees discuss work with one another and their supervisor. Employees in these work stations are in a back office, because they have low customer contact and little service customization.

Process Structure in Manufacturing

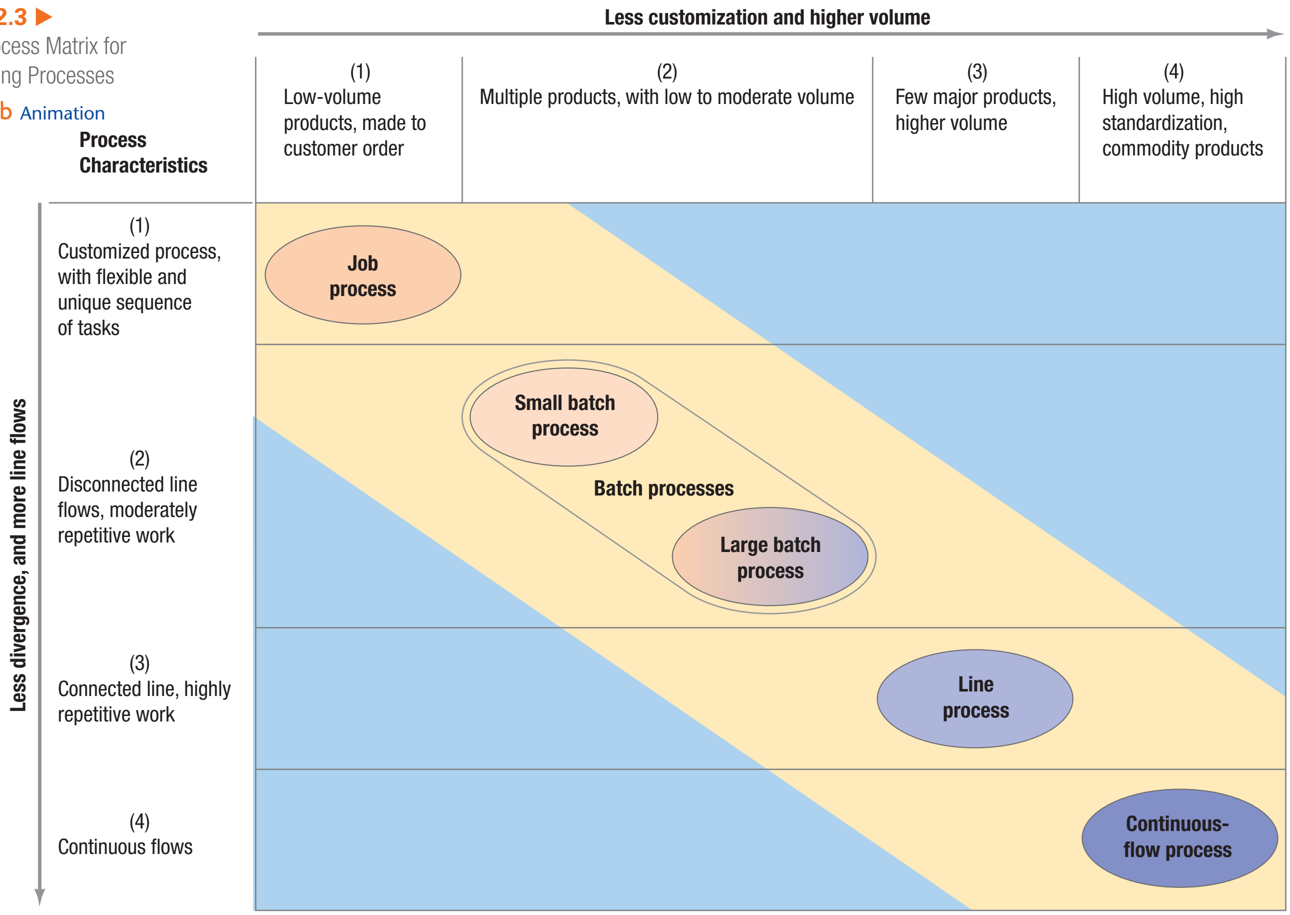
Many processes at a manufacturing firm are actually services to internal or external customers, and so the previous discussion on services applies to them. Similarly, manufacturing processes can be found in service firms. Clarity comes when viewing work at the process level, rather than the organizational level. Here we focus instead on the manufacturing processes. Because of the differences between service and manufacturing processes, we need a different view on process structure.

Product–Process Matrix

The product–process matrix, shown in Figure 2.3, brings together three elements: (1) volume, (2) product customization, and (3) process characteristics. It synchronizes the product to be manufactured with the manufacturing process itself.

A good strategy for a manufacturing process depends first and foremost on volume. Customer contact, a primary feature of the customer-contact matrix for services, normally is not a consideration for manufacturing processes (although it *is* a factor for the many service processes throughout manufacturing firms). For many manufacturing processes, high product customization means lower volumes for many of the steps in the process. The vertical dimension of the product–process matrix deals with the same two characteristics in the customer-contact matrix: process divergence and flow. Each manufacturing process should be analyzed on these two dimensions, just as was done for a service process.

FIGURE 2.3 ▶
Product-Process Matrix for Manufacturing Processes
MyOMLab Animation



Manufacturing Process Structuring

Figure 2.3 shows several desirable positions (often called *process choices*) in the product–process matrix that effectively connect the manufactured product with the process. **Process choice** is the way of structuring the process by organizing resources around the process or organizing them around the products. Organizing around the process means, for example, that all milling machines are grouped together and process all products or parts needing that kind of transformation. Organizing around the product means bringing together all the different human resources and equipment needed for a specific product and dedicating them to producing just that product. The manager has four process choices, which form a continuum, to choose from: (1) job process, (2) batch process, (3) line process, and (4) continuous-flow process. As with the customer-contact matrix, it is unlikely that a manufacturing process can be a top performer if its position is too far from the diagonal. The fundamental message in Figure 2.3 is that the best choice for a manufacturing process depends on the volume and degree of customization required of the process. The process choice might apply to an entire manufacturing process or just one subprocess nested within it.

process choice
A way of structuring the process by organizing resources around the process or organizing them around the products.

Job Process A **job process** creates the flexibility needed to produce a wide variety of products in significant quantities, with considerable divergence in the steps performed. Customization is high and volume for any one product is low. The workforce and equipment are flexible to handle considerable task divergence. Companies choosing job processes often bid for work. Typically, they make products to order and do not produce them ahead of time. Each new order is handled as a single unit—as a job. Examples are machining a metal casting for a customized order or producing customized cabinets.

With a job process, all equipment and workers capable of certain types of work are positioned together. Because customization is high and most jobs have a different sequence of steps, this process choice creates flexible flows through the operations rather than a line flow.

job process
A process with the flexibility needed to produce a wide variety of products in significant quantities, with considerable divergence in the steps performed.

Batch Process The batch process is by far the most common process choice found in practice, leading to terms such as *small batch* or *large batch* to further distinguish one process choice from another. A **batch process** differs from the job process with respect to volume, variety, and quantity. The primary difference is that volumes are higher because the same or similar products or parts going into them are produced repeatedly. Some of the components going into the final product may be processed in advance. Production lots are handled in larger quantities (or *batches*) than they are with job processes. A batch of one product (or component part going into it or perhaps other products) is processed, and then production is switched to the next one. Eventually, the first product is produced again. A batch process has average or moderate volumes, but process divergence is still too great to warrant dedicating a separate process for each product. The process flow is flexible, but more dominant paths emerge than at a job process, and some segments of the process have a line flow. Examples of a batch process are making standard components that feed an assembly line or some processes that manufacture capital equipment.

batch process
A process that differs from the job process with respect to volume, variety, and quantity.

Line Process A **line process** lies between the batch and continuous processes on the continuum; volumes are high and products are standardized, which allows resources to be organized around particular products. Divergence is minimal in the process or line flows, and little inventory is held between the processing steps. Each step performs the same process over and over, with little variability in the products manufactured. Production and material handling equipment is specialized. Products created by a line process include the assembly of computers, automobiles, appliances, and toys.

Standard products are produced in advance of their need and held in inventory so that they are ready when a customer places an order. Product variety is possible by careful control of the addition of standard options to the main product.

line process
A process that lies between the batch and continuous processes on the continuum; volumes are high and products are standardized, which allows resources to be organized around particular products.

Continuous-Flow Process A **continuous-flow process** is the extreme end of high-volume standardized production, with rigid line flows. Process divergence is negligible. Its name derives from the way materials move through the process. Usually, one primary material (such as a liquid, a gas, or a powder) moves without stopping through the process. A continuous-flow process differs from a line process in one important respect: Materials (be they undifferentiated or discrete) flow through the process without stopping until the whole batch is finished. The time span can be several shifts or even several months. Examples of a continuous-flow process are petroleum refining; chemical processes; paper manufacturing; and processes making steel, soft drinks, and food.

continuous-flow process
The extreme end of high-volume standardized production and rigid line flows, with production not starting and stopping for long time intervals.

Production and Inventory Strategies

Strategies for manufacturing processes differ from those in services not only because of low customer contact and involvement but also because of the ability to use inventories not only as purchased materials but also in the form of subassemblies or finished products. As we learned in Chapter 1, there are clearly exceptions to this rule as Avis has an inventory of autos to rent, and FedEx has an inventory of in-process parcels. Design-to-order, make-to-order, assemble-to-order, and make-to-stock strategies are four approaches to inventory that should be coordinated with process choice.

design-to-order strategy

A strategy that involves designing new products that do not currently exist, and then manufacturing them to meet unique customer specifications.

make-to-order strategy

A strategy used by manufacturers that make products to customer specifications in low volumes.

assemble-to-order strategy

A strategy for producing a wide variety of products from relatively few subassemblies and components after the customer orders are received.

postponement

The strategy of delaying final activities in the provision of a product until the orders are received.

mass customization

The strategy that uses highly divergent processes to generate a wide variety of customized products at reasonably low costs.

make-to-stock strategy

A strategy that involves holding items in stock for immediate delivery, thereby minimizing customer delivery times.

mass production

A term sometimes used in the popular press for a line process that uses the make-to-stock strategy.

Design-to-Order Strategy A firm uses a **design-to-order strategy** when it can design new products that do not currently exist, and then manufacture them to meet unique customer specifications. Typically a job process is employed to create a highly customized product, such as a designer pair of shoes for a particular client.

Make-to-Order Strategy Manufacturers that make products to customer specifications in low volumes tend to use the **make-to-order strategy**, coupling it with job or small batch processes. Even though the product is based on a standard design, it is a more complex process than assembling a final product from standard components. This strategy provides a high degree of customization and typically uses job or small batch processes. The processes have high divergence. Specialized medical equipment, castings, and expensive homes are suited to the make-to-order strategy.

Assemble-to-Order Strategy The **assemble-to-order strategy** is an approach to producing a wide variety of products from relatively few subassemblies and components after the customer orders are received. Typical competitive priorities are variety and fast delivery times. The assemble-to-order strategy often involves a line process for assembly and a batch process for fabrication. Because they are devoted to manufacturing standardized components and subassemblies in high volumes, the fabrication processes focus on creating appropriate amounts of component inventories for the assembly processes. Once the specific order from the customer is received, the assembly processes create the product from standardized components and subassemblies produced by the fabrication processes.

Stocking finished products would be economically prohibitive because the numerous possible options make forecasting relatively inaccurate. Thus, the principle of **postponement** is applied, whereby the final activities in the provision of a product are delayed until the orders are received. The assemble-to-order strategy is also linked to **mass customization**, where highly divergent processes generate a wide variety of customized products at reasonably low costs. Both postponement and mass customization are covered more fully in Chapter 12, "Designing Effective Supply Chains."

Make-to-Stock Strategy Manufacturing firms that hold items in stock for immediate delivery, thereby minimizing customer delivery times, use a **make-to-stock strategy**. This strategy is feasible for standardized products with high volumes and reasonably accurate forecasts. It is the inventory strategy of choice for line or continuous-flow processes. Examples of products produced with a make-to-stock strategy include garden tools, electronic components, soft drinks, and chemicals.

Combining a line process with the make-to-stock strategy is sometimes called **mass production**. It is what the popular press commonly envisions as the classical manufacturing process, because the environment is stable and predictable, with workers repeating narrowly defined tasks with low divergence.

Layout

Selecting process structures for the various processes housed in a facility is a strategic decision, but must be followed by a more tactical decision—creating a layout. A *layout* is the physical arrangement of operations (or departments) created from the various processes and puts them in tangible form. For organizational purposes, processes tend to be clustered together into operations or departments. An *operation* is a group of human and capital resources performing all or part of one or more processes. For example, an operation could be several customer service representatives in a customer reception area; a group of machines and workers producing cell phones; or a marketing department. Regardless of how processes are grouped together organizationally, many of them cut across departmental boundaries. The flows across departmental lines could be informational, services, or products. Process structures that create more flows across departmental lines, as with job or batch processes, are the most challenging layout problems. Supplement K, "Layout," provides a more in-depth analysis of how to gather information and develop detailed layout plans.

Process Strategy Decisions

Having covered process structure decisions in both service and manufacturing organizations, we turn our attention now to the other three major process strategy decisions shown in Figure 2.1—customer involvement, resource flexibility, and capital intensity.

Customer Involvement

Customer involvement reflects the ways in which customers become part of the process and the extent of their participation. As illustrated in Managerial Practice 2.1, it is especially important for many service processes such as eBay, particularly if customer contact is (or should be) high.

Possible Advantages The advantages of a more customer-focused process might increase the net value to the customer. Some customers seek active participation in and control over the service process, particularly if they will enjoy savings in both price and time. The manager must assess whether advantages outweigh disadvantages, judging them in terms of the competitive priorities and customer satisfaction. More customer

MANAGERIAL PRACTICE 2.1 Customer Involvement at eBay

Kristoffer Tripplaar/Alamy

At any given time eBay has approximately 650 million listings worldwide, and yet its workforce consists of just 31,800 employees. The explanation? Customers do most of the work in eBay's buying and selling processes.

Most manufacturers do not have to contend with customers waltzing around their shop floors, showing up intermittently and unannounced. Such customer contact can introduce considerable variability, disrupting carefully designed production processes. Costs and quality can be adversely affected. While customer contact is an issue even with manufacturers (each process does have at least one customer), extensive customer contact and involvement are business as usual for many processes of service providers. Customers at restaurants or rental car agencies are directly involved in performing the processes. The area where the sales person interacts with the customer *is* the shop floor.

How much should customers be involved in a process, so as to provide timely delivery and consistent quality, and at sustainable cost? Various ways are available—some accommodate customer-introduced variability and some reduce it. eBay provides two services: It provides sellers a platform for selling their goods or services, and it provides buyers a platform to find the goods and services they want. From a business perspective, providing these two services generates a high degree of variability in the demands for the company's resources. eBay illustrates one way to accommodate that kind of variability—provide an online auction house. As an online auction house, eBay accommodates high volumes as well as service order variability from customers seeking to buy and sell an endless number of items. eBay customers also have variability in technological capability, some with considerable Internet experience and some needing more handholding. Such variability would greatly complicate workforce scheduling if eBay's customers were not involved in many of its processes. eBay's process strategy utilizing customer involvement has been successful. Founded in 1995 in California, it now has 145 million active buyers globally buying and selling more than 650 million listed items with revenue of about $16.5 billion per year. It connects hundreds of millions of people around the world every day with only 31,800 employees. This relatively small workforce is possible in the face of customer-induced variability because its customers perform virtually all of the selling and buying processes through the e-commerce platform eBay.com and other vertical shopping sites. When the customer is responsible for much of the work, the right labor is provided at the right moment.

Source: Frances X. Frei, "Breaking the Trade-Off between Efficiency and Service," *Harvard Business Review* (November 2006), pp. 93–101; **http://en.wikipedia.org/wiki/Ebay** (May 31, 2014); **https://finance.yahoo.com/q/pr?s=EBAY+Profile** (May 31, 2014); **http://www.ebayinc.com/who_we_are/one_company** (May 31, 2014).

involvement can mean better quality, faster delivery, greater flexibility, and even lower cost. Self-service is the choice of many retailers, such as gasoline stations, supermarkets, and bank services. Manufacturers of products (such as toys, bicycles, and furniture) may also prefer to let the customer perform the final assembly because product, shipping, and inventory costs frequently are lower. In fact, IKEA Furniture Company's business model is based on customers being actively involved in its processes.

Customer involvement can also help coordinate across the supply chain (see Chapter 14, "Integrating the Supply Chain"). Emerging technologies allow companies to engage in an active dialogue with customers and make them partners in creating value and forecasting future demand. Suppliers to automobile companies can be close collaborators in the process of developing new vehicles and are no longer passive providers of materials and services. The same is true for distributors. Walmart does more than just distribute Procter & Gamble's products: It shares daily sales information and works with Procter & Gamble in managing inventories and warehousing operations.

Ramin Talaie/Corbis

A customer at Starbucks, a large coffee shop chain, places his order in the correct way. By structuring the ordering process for counter clerks and customers, Starbucks can deal efficiently with the variety in products offered, and with no hit on the service experience.

Jetta Productions/Getty Images

A car mechanic must be flexibly cross-trained at many different tasks in order to repair a wide variety of cars from different manufacturers.

Possible Disadvantages Customer involvement is not always a good idea. In some cases, giving the customer more active contact in a service process will just be disruptive, making the process less efficient. Managing the timing and volume of customer demands becomes more challenging if the customer is physically present and expects prompt delivery. Exposing the facilities and employees to the customer can have important quality implications (favorable or unfavorable). Such changes make interpersonal skills a prerequisite to the service provider's job, but higher skill levels come at a cost. It also might mean having many smaller decentralized facilities closer to the various customer concentration areas if the customer comes to the service providers.

Resource Flexibility

Just as managers must account for customer contact when making customer involvement decisions, so must they account for process divergence and diverse process flows when making resource flexibility decisions in Figure 2.1. For example, high task divergence and flexible process flows require more flexibility of the process's resources—its employees, facilities, and equipment. Employees need to perform a broad range of duties, and equipment must be general purpose. Otherwise, resource utilization will be too low for economical operations.

flexible workforce

A workforce whose members are capable of doing many tasks, either at their own workstations or as they move from one workstation to another.

Workforce Operations managers must decide whether to have a **flexible workforce**. Members of a flexible workforce are capable of doing many tasks, either at their own workstations or as they move from one workstation to another. However, such flexibility often comes at a cost, requiring greater skills and thus more training and education. Nevertheless, benefits can be large: Worker flexibility can be one of the best ways to achieve reliable customer service and alleviate capacity bottlenecks. Resource flexibility helps to absorb the feast-or-famine workloads in individual operations that are caused by low-volume production, divergent tasks, flexible flows, and fluid scheduling.

The type of workforce required also depends on the need for volume flexibility. When conditions allow for a smooth, steady rate of output, the likely choice is a permanent workforce that expects regular full-time employment. If the process is subject to hourly, daily, or seasonal peaks and valleys in demand, the use of part-time or temporary employees to supplement a smaller core of full-time employees may be the best solution. However, this approach may not be practical if knowledge and skill requirements are too high for a temporary worker to grasp quickly.

MyOMLab

Tutor 2.1 in MyOMLab demonstrates how to do break-even analysis for equipment selection.

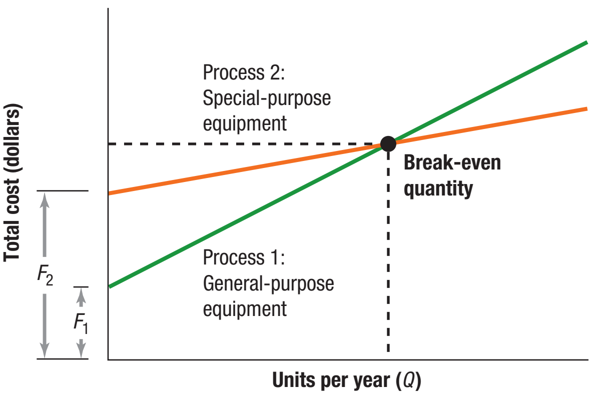
Equipment Low volumes mean that process designers should select flexible, general-purpose equipment. Figure 2.4 illustrates this relationship by showing the total cost lines for two different types of equipment that can be chosen for a process. Each line represents the total annual cost of the process at different volume levels. It is the sum of fixed costs and variable costs (see Supplement A, "Decision Making Models"). When volumes are low (because customization is high), process 1 is the better choice. It calls for inexpensive general-purpose equipment, which keeps investment in equipment low and makes fixed costs (F_1) small. Its variable unit cost is high, which gives its total cost line a relatively steep slope. Process 1 does the job, but not at peak efficiency.

Conversely, process 2 is the better choice when volumes are high and customization is low. Its advantage is low variable unit cost, as reflected in the flatter total cost line. This efficiency is possible when customization is low because the equipment can be designed for a narrow range of products or tasks. Its disadvantage is high equipment investment and, thus, high fixed costs (F_2). When annual volume produced is high enough, spreading these fixed costs over more units produced, the advantage of low variable costs more than compensates for the high fixed costs.

The break-even quantity in Figure 2.4 is the quantity at which the total costs for the two alternatives are equal. At quantities beyond this point, the cost of process 1 exceeds that of process 2. Unless the firm expects to sell more than the break-even amount, which is unlikely with high customization and low volume, the capital investment of process 2 is not warranted.

FIGURE 2.4

Relationship between Process Costs and Product Volume



Capital Intensity

Capital intensity is the mix of equipment and human skills in the process; the greater the cost of equipment relative to the cost of labor, the greater is the capital intensity. As the capabilities of technology increase and its costs decrease, managers face an ever-widening range of choices, from operations utilizing very little automation to those requiring task-specific equipment and little human intervention. **Automation** is a system, process, or piece of equipment that is self-acting and self-regulating. Although automation is often thought to be necessary to gain competitive advantage, it has both advantages and disadvantages. Thus, the automation decision requires careful examination.

automation

A system, process, or piece of equipment that is self-acting and self-regulating.

fixed automation

A manufacturing process that produces one type of part or product in a fixed sequence of simple operations.

flexible (or programmable) automation

A manufacturing process that can be changed easily to handle various products.

industrial robot

Versatile, computer-controlled machine programmed to perform various tasks.

Automating Manufacturing Processes Substituting labor-saving capital equipment and technology for labor has been a classic way of improving productivity and quality consistency in manufacturing processes. If investment costs are large, automation works best when volume is high, because more customization typically means reduced volume. Gillette, for example, spent $750 million on the production lines and robotics that gave it a capacity to make 1.2 billion razor cartridges a year. The equipment is complicated and expensive. Only with such high volumes could this line process produce the product at a price low enough that consumers could afford to buy it.

One big disadvantage of capital intensity can be the prohibitive investment cost for low-volume operations (see Figure 2.4). Generally, capital-intensive operations must have high utilization to be justifiable. Also, automation does not always align with a company's competitive priorities. If a firm offers a unique product or high-quality service, competitive priorities may indicate the need for hand labor and individual attention rather than new technology. A case in point is the downstream processes in Gillette's supply chain that package and store the razor cartridges. It customizes the packaging for different regions of the world, so that volumes for any one type of package are much lower. As a result of the low volumes, Gillette does not use expensive automation for these processes. In fact, it outsources them. It produces razor cartridges to stock using highly automated processes and then packages them in customized fashion at remote locations on demand.

Manufacturers use two types of automation: (1) fixed and (2) flexible (or programmable). Particularly appropriate for line and continuous-flow process choices, **fixed automation** produces one type of part or product in a fixed sequence of simple operations. Operations managers favor fixed automation when demand volumes are high, product designs are stable, and product life cycles are long. These conditions compensate for the process's two primary drawbacks: (1) large initial investment cost and (2) relative inflexibility. However, fixed automation maximizes efficiency and yields the lowest variable cost per unit if volumes are high.

Flexible (or programmable) automation can be changed easily to handle various products. The ability to reprogram machines is useful for both low-customization and high-customization processes. In the case of high customization, a machine that makes a variety of products in small batches can be programmed to alternate between products. When a machine has been dedicated to a particular product or family of products, as in the case of low customization and a line flow, and the product is at the end of its life cycle, the machine can simply be reprogrammed with a new sequence of tasks for a new product. An **industrial robot**, which is a versatile, computer-controlled machine programmed to perform various tasks, is a classic example of flexible automation. These "steel-collar" workers operate independently of human control. A robot's arm has up to six standard movements. The robot's "hand" can be changed to perform different tasks, such as materials handling, assembly, and testing.

Automating Service Processes Using capital inputs as a labor-saving device is also possible for service processes. In educational services, for example, long-distance learning technology now can supplement or even replace the traditional classroom experience by using books, computers, Web sites, and videos as facilitating goods that go with the service. Justifying technology need not be limited to cost reduction. Sometimes, it can actually allow more task divergence by making available a wide menu of choices to the customer. It can also improve quality by being more consistent.

James Hardy/PhotoAlto/Alamy

R.R. Donnelly has been able to achieve flexible automation by receiving books digitally and preparing them to go to press electronically. This allows the company to put books on press more quickly and print smaller more manageable quantities in a single print run.

David R. Frazier/Newscom

Regional automated mail sorting facility in Boise, Idaho. Automating service processes in high volume environments such as these save labor and justify expensive capital investments.

The need for volume to justify expensive automation is just as valid for service processes as for manufacturing processes. Increasing the volume lowers the cost per dollar of sales. Volume is essential for many capital-intensive processes in the transportation, communications, and utilities industries.

Economies of Scope If capital intensity is high, resource flexibility usually is low. In certain types of manufacturing operations, such as machining and assembly, programmable automation breaks this inverse relationship between resource flexibility and capital intensity. It makes possible both high capital intensity and high resource flexibility, creating economies of scope. **Economies of scope** reflect the ability to produce multiple products more cheaply in combination than separately. In such situations, two conflicting competitive priorities—customization and low price—become more compatible. However, taking advantage of economies of scope requires that a family of parts or products have enough collective volume to utilize equipment fully.

economies of scope

Economies that reflect the ability to produce multiple products more cheaply in combination than separately.

Economies of scope also apply to service processes. Consider, for example, Disney whose managers used the Internet to reap the benefits of economies of scope. They aggressively linked their Internet processes with one another and with other parts of Disney. A flexible technology that handles many services together can be less expensive than handling each one separately, particularly when the markets are not too volatile.

Strategic Fit

The manager should understand how the four major process decisions tie together, so as to spot ways of improving poorly designed processes. The choices should fit the situation and each other. When the fit is more *strategic*, the process will be more effective. We examine services and manufacturing processes, looking for ways to test for strategic fit.

Decision Patterns for Service Processes

After analyzing a process and determining its position on the customer-contact matrix in Figure 2.2, it may be apparent that it is improperly positioned, either too far to the left or right, or too far to the top or bottom. Opportunities for improvement become apparent. Perhaps, more customization and customer contact is needed than the process currently provides. Perhaps, instead, the process is too divergent, with unnecessarily flexible flows. Reducing divergence might reduce costs and improve productivity.

The process should reflect its desired competitive priorities. Front offices generally emphasize top quality and customization, whereas back offices are more likely to emphasize low-cost operation, consistent quality, and on-time delivery. The process structure selected then points the way to appropriate choices on customer involvement, resource flexibility, and capital intensity. High customer contact at a front-office service process means:

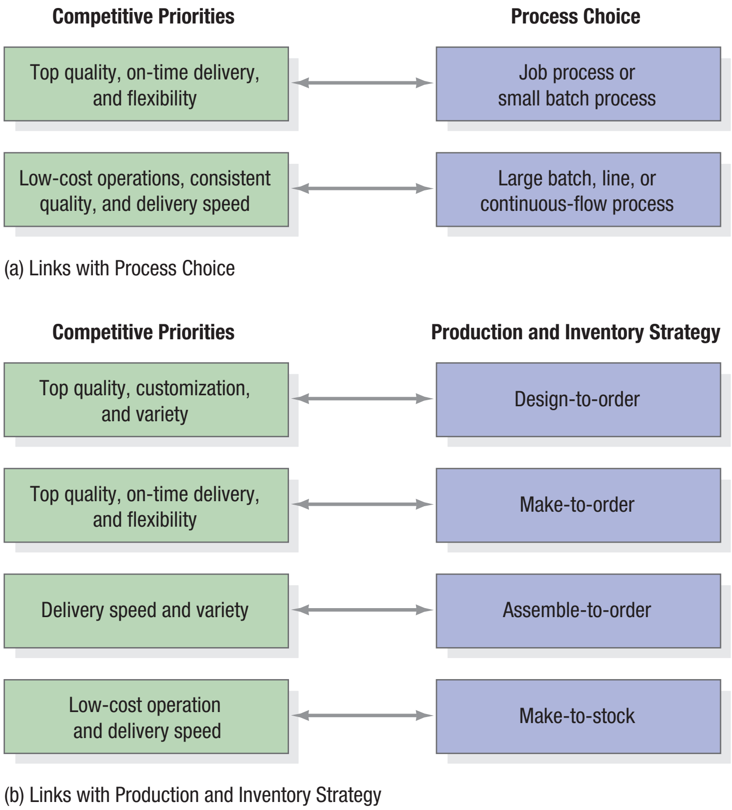
1. *Process Structure.* The customer (internal or external) is present, actively involved, and receives personal attention. These conditions create processes with high divergence and flexible process flows.
2. *Customer Involvement.* When customer contact is high, customers are more likely to become part of the process. The service created for each customer is unique.
3. *Resource Flexibility.* High process divergence and flexible process flows fit with more flexibility from the process's resources—its workforce, facilities, and equipment.
4. *Capital Intensity.* When volume is higher, automation and capital intensity are more likely. Even though higher volume is usually assumed in the back office, it is just as likely to be in the front office for financial services. Information technology is a major type of automation at many service processes, which brings together both resource flexibility and automation.

Of course, this list provides general tendencies rather than rigid prescriptions. Exceptions can be found, but these relationships provide a way of understanding how service process decisions can be linked coherently.

Decision Patterns for Manufacturing Processes

Just as a service process can be repositioned in the customer-contact matrix, a manufacturing process can also be moved in the product–process matrix. Changes can be made either in the horizontal direction of Figure 2.3 by changing the degree of customization and volume, or they can be moved in the vertical direction by changing process divergence. Competitive priorities must be considered when translating strategy into specific manufacturing processes. Figure 2.5 shows some usual tendencies found in practice. Job and small batch processes are usual choices if top quality, on-time delivery, and flexibility (customization, variety, and volume flexibility) are given primary emphasis. Large batch, line, and continuous-flow processes match up with an emphasis on low-cost operations, consistent quality, and delivery speed.

The production and inventory strategy should also be chosen to be consistent with the competitive priorities emphasized. As shown in Figure 2.5, the design-to-order strategy is consistent with top quality, customization, and variety. The focus is on meeting the unique needs of the customers by specifically designing a variety of products according to the customer specifications. The make-to-order strategy matches up with flexibility (particularly customization) and top quality. Because delivery speed is more difficult, meeting due dates and on-time delivery get the emphasis on the time dimension. The assemble-to-order strategy allows delivery speed and flexibility (particularly variety) to be achieved, whereas the make-to-stock strategy is the usual choice if delivery speed and low-cost operations are emphasized. Keeping an item in stock ensures quick delivery because it is generally available when needed, without delays in producing it. High volumes open up opportunities to reduce costs.



▲ **FIGURE 2.5**
Links of Competitive Priorities with Manufacturing Strategy

The process structure selected once again points the way to appropriate choices on customer involvement, resource flexibility, and capital intensity. High volumes per part type at a manufacturing process typically mean:

1. *Process Structure.* High volumes, combined with a standard product, make a line flow possible. It is just the opposite where a job process produces to specific customer orders.
2. *Customer Involvement.* Customer involvement is not a factor in most manufacturing processes, except for choices made on product variety and customization. Less discretion is allowed with line or continuous-flow processes to avoid the unpredictable demands required by customized orders.
3. *Resource Flexibility.* When volumes are high and process divergence is low, flexibility is not needed to utilize resources effectively, and specialization can lead to more efficient processes.
4. *Capital Intensity.* High volumes justify the large fixed costs of an efficient operation.

Gaining Focus

In the past, new services or products often were added to a facility in the name of better utilizing fixed costs and keeping everything under the same roof. The result was a jumble of competitive priorities, process structures, and technologies. In the effort to do everything, nothing was done well.

Focus by Process Segments A facility's operations often can neither be characterized nor actually designed for one set of competitive priorities and one process choice. At a services facility, some parts of the process might seem like a front office and other parts like a back office. Such arrangements can be effective, provided that sufficient focus is given to each process by the management segmenting them into separate operations that are relatively autonomous.

Plants within plants (PWPs) are different operations within a facility with individualized competitive priorities, processes, and workforces under the same roof. Boundaries for PWPs may be established by physically separating subunits or simply by revising organizational relationships. At each PWP, customization, capital intensity volume, and other relationships are crucial and must be complementary. The advantages of PWPs are fewer layers of management, greater ability to rely on team problem solving, and shorter lines of communication between departments.

plants within plants (PWPs)
Different operations within a facility with individualized competitive priorities, processes, and workforces under the same roof.

AP Photo/Mike Wintroath

Focused factories are not just found in manufacturing. This single-specialty facility focuses just on heart surgery and has all the advanced resources need that cannot be provided by a general hospital. Another example is the Toronto-based Shouldice Clinic, which focuses just on hernias.

Focused Service Operations Service industries also implement the concepts of focus and PWPs. Specialty retailers opened stores with smaller, more accessible spaces. These focused facilities generally chipped away at the business of large department stores. Using the same philosophy, some department stores now focus on specific customers or products. Remodeled stores create the effect of many small boutiques under one roof.

Focused Factories Hewlett-Packard, Rolls-Royce, Japan's Ricoh and Mitsubishi, and Britain's Imperial Chemical Industries PLC are some of the firms that created **focused factories**, splitting large plants that produced all the company's products into several specialized smaller plants. The theory is that narrowing the range of demands on a facility will lead to better performance because management can concentrate on fewer tasks and lead a workforce toward a single goal.

Strategies for Change

The four major process decisions represent broad, strategic issues and define the nature of the processes a firm needs to compete effectively. However, decisions that are made must be translated into actual process designs or redesigns. There are two different but complementary philosophies for process design and change: (1) process reengineering and (2) process improvement. Process analysis, supported by the tools described later, is needed regardless of whether reengineering or process improvement is attempted. An individual or a whole team examines the process and looks for ways to streamline tasks, eliminate whole processes entirely, cut expensive materials or services, improve the environment, or make jobs safer. By comprehensively analyzing the process, one must find the ways to trim costs and delays and to improve customer satisfaction.

Process Reengineering

Reengineering is the fundamental rethinking and radical redesign of processes to improve performance dramatically in terms of cost, quality, service, and speed. Process reengineering is about reinvention rather than incremental improvement. It is strong medicine and not always needed or successful. Pain, in the form of layoffs and large cash outflows for investments in information technology, almost always accompanies massive change. However, reengineering processes can have big payoffs. Table 2.2 lists the key elements of the overall approach.

focused factories

The result of a firm's splitting large plants that produced all the company's products into several specialized smaller plants.

reengineering

The fundamental rethinking and radical redesign of processes to improve performance dramatically in terms of cost, quality, service, and speed.

TABLE 2.2 KEY ELEMENTS OF REENGINEERING

Element	Description
Critical processes	The emphasis of reengineering should be on core business processes. Normal process-improvement activities can be continued with the other processes.
Strong leadership	Senior executives must provide strong leadership for reengineering to be successful. Otherwise, cynicism, resistance ("we tried that before"), and boundaries between departments can block radical changes.
Cross-functional teams	A team, consisting of members from each functional area affected by the process change, is charged with carrying out a reengineering project. Self-managing teams and employee empowerment are the rule rather than the exception.
Information technology	Information technology is a primary enabler of process engineering. Most reengineering projects design processes around information flows, such as customer order fulfillment.
Clean-slate philosophy	Reengineering requires a "clean-slate" philosophy—that is, starting with the way the customer wants to deal with the company. To ensure a customer orientation, teams begin with internal and external customer objectives for the process.
Process analysis	Despite the clean-slate philosophy, a reengineering team must understand things about the current process: what it does, how well it performs, and what factors affect it. The team must look at every procedure involved in the process throughout the organization.

Reengineering has led to many successes and will continue to do so. However, it is not simple or easily done, nor is it appropriate for all processes or all organizations. The best understanding of a process, and how to improve it, often lies with the people who perform the work each day, not with cross-functional teams or top management.

Process Improvement

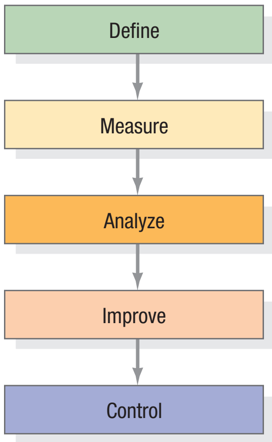
Process improvement is the systematic study of the activities and flows of each process to improve it. Its purpose is to "learn the numbers," understand the process, and dig out the details. Once a process is really understood, it can be improved. The relentless pressure to provide better quality at a lower price means that companies must continually review all aspects of their operations. Process improvement goes on, whether or not a process is reengineered. There is always a better way. Most processes can be improved if someone thinks of a way and implements it effectively. Indeed, companies will either adapt processes to the changing needs of customers or cease to exist. Long-term success comes from managers and employees who really understand their businesses. But all too often, highly publicized efforts that seem to offer quick-fix solutions fail to live up to expectations over the long haul, be they programs for conceptualizing a business vision, conducting culture transformation campaigns, or providing leadership training.

process improvement
The systematic study of the activities and flows of each process to improve it.

Process Analysis

Process analysis is the documentation and detailed understanding of how work is performed and how it can be redesigned. Looking at the strategic issues can help identify opportunities for improvement. Do gaps exist between a process's competitive priorities and its current competitive capabilities, as was found for the assessment of operations strategy at a credit card division in Chapter 1, "Using Operations to Create Value"? Do multiple measures of cost, top quality, quality consistency, delivery speed, and on-time delivery meet or exceed expectations? Is there a good *strategic fit* in the process? If the process provides a service, does its position on the customer-contact matrix (see Figure 2.2) seem appropriate? How does the degree of customer contact match up with process structure, customer involvement, resource flexibility, and capital intensity? Similar questions should be asked about manufacturing processes regarding the strategic fit between process choice, volume, and product customization.

Process analysis begins with identifying and defining a new opportunity for improvement and ends with implementing and controlling a revised process, and which we capture through the Six Sigma Process Improvement Model. Other approaches to process improvement are statistical process control and process capability analysis, discussed in Chapter 3, "Managing Quality," and value stream mapping, discussed in Chapter 6, "Designing Lean Systems." We avoid overlap by covering each technique just once, while bringing out the essence of the approach covered in each chapter. The chapters do have a shared goal: better processes.



▲ **FIGURE 2.6**
Six Sigma Process Improvement Model

Six Sigma Process Improvement Model Figure 2.6 shows the Six Sigma Process Improvement Model, a five-step procedure that leads to improvements in-process performance. This model can be applied to projects involving incremental improvements to processes or to projects requiring major changes, including a redesign of an existing process or the development of a new process.

The following steps comprise the model:

- *Define*. The scope and boundaries of the process to be analyzed are first established. Is it a broad process that stretches across the whole organization, involving many steps and many employees, or is it a more narrowly bracketed nested subprocess that is just part of one person's job? A process's scope can be too narrow or too broad. For example, a broadly defined process that outstrips the resources available, sometimes called "trying to boil the ocean," is doomed because it will increase employee frustration without producing any results. The resources that management assigns to improving or reengineering a process should match the scope of the process. Once scope is established, determine the characteristics of the process's output that are critical to customer satisfaction and identify any gaps between these characteristics and the process's capabilities. Get a picture of the current process by documenting it using techniques outlined in this chapter.
- *Measure*. It is important to have good performance measures to evaluate a process for clues on how to improve it. **Metrics** are performance measures for the process and the steps within it. A good place to start is with competitive priorities, but they need to be specific. The analyst creates multiple measures of quality, customer satisfaction, time to perform each step or the whole process, cost, errors, safety, environmental measures, on-time delivery, flexibility, and the like. Once the metrics are identified, it is time to collect information on how the process is currently performing on each one. Measurement can be rough-cut estimates or quite extensive. It is important to quantify the work the process does that affects the gap. Select what to measure, identify data sources, and prepare a data collection plan.
- *Analyze*. Use the data on measures to perform process analysis to determine where improvements are necessary. A careful analysis of the process and its performance on the selected metrics should

metrics
Performance measures that are established for a process and the steps within it.

uncover *disconnects*, or gaps, between actual and desired performance. Illogical, missing, or extraneous steps can cause performance gaps. They can also be caused by metrics that reinforce the silo mentality of individual departments when the process spans across several departments. The analyst or design team should dig deep to find the root causes of performance gaps. For instance, techniques for analyzing wait times and delays can provide important information (see Supplement B, "Waiting Line Models" and MyOMLab Supplement E, "Simulation"). Whether or not major redesign is necessary, establish procedures to make the desired outcome routine.

- *Improve*. Using analytical and creative thinking, the design team generates a long list of ideas for improvements. These ideas are then sifted and analyzed. Ideas that are justifiable, where benefits outweigh costs, are reflected in a new process design that can meet the new performance objectives. The new design should be documented "as proposed." Combining the new process design with the documentation of the current process gives the analysts clear before and after pictures. The new documentation should make clear how the revised process will work and the performance expected for the various metrics used. Implement the changes.
- *Control*. After the implementation, monitor the process to make sure that high performance levels are maintained. Once again, data analysis tools can be used to control the process. Implementation is more than developing a plan and carrying it out. Many processes have been redesigned effectively, but never get implemented. People resist change: "We have always done it that way" or "we tried that before." Widespread participation in process analysis is essential, not only because of the work involved but also because it builds commitment. It is much easier to implement something that is partly your own idea. In addition, special expertise may be needed, such as for developing software. New jobs and skills may be needed, involving training and investments in new technology. Implementation and control brings to life the steps needed to bring the redesigned process online. Management or the steering committee must make sure that the implementation project goes according to schedule.

Green Belt

An employee who achieved the first level of training in a Six Sigma program and spends part of his or her time teaching and helping teams with their projects.

Black Belt

An employee who reached the highest level of training in a Six Sigma program and spends all of his or her time teaching and leading teams involved in Six Sigma projects.

Master Black Belt

Full-time teachers and mentors to several Black Belts.

Successful users have found that it is essential to rigorously follow the steps in the Six Sigma Improvement Model, which is sometimes referred to as the *DMAIC process* (whose name comes from using the first letter of each step in the model). To accomplish the goals of Six Sigma, employees must be trained in the "whys" and the "how-tos" of process performance and what it means to customers, both internal and external. Successful firms using Six Sigma develop a cadre of internal teachers who then are responsible for teaching and assisting teams involved in a process-improvement project. These teachers have different titles depending on their experience and level of achievement. "**Green Belts**" devote part of their time to teaching and helping teams with their projects and the rest of their time to their normally assigned duties. "**Black Belts**" are full-time teachers and leaders of teams involved in Six Sigma projects. Finally, "**Master Black Belts**" are full-time teachers who review and mentor "Black Belts."

flowchart

A diagram that traces the flow of information, customers, equipment, or materials through the various steps of a process.

Documenting and Evaluating the Process

Three major techniques for effectively documenting and evaluating processes are (1) flowcharts, (2) work measurement techniques, and (3) process charts. They allow you to "lift the lid and peer inside" to see how an organization does its work. You can see how a process operates, at any level of detail, and how well it is performing. Trying to create one of these charts might even reveal a lack of any established process. It may not be a pretty picture, but it is how work actually gets done. Techniques for documenting the process lend themselves to finding performance gaps, generating ideas for process improvements, and documenting the look of a redesigned process.

Wavebreak Media Ltd./Alamy

Young designer presenting a flow chat during a meeting. The use of flowcharts can help in documenting and evaluating processes.

Flowcharts

A **flowchart** traces the flow of information, customers, equipment, or materials through the various steps of a process. Flowcharts are also known as flow diagrams, process maps, relationship maps, or blueprints. Flowcharts have no precise format and typically are drawn with boxes (with a brief description of the step inside), and with lines and arrows to show sequencing. The rectangle (□) shape is the usual choice for a box, although other shapes (○, ⬭, ⬡, ▽, or ▱) can differentiate between different types of steps (e.g., operation, delay, storage, and inspection). Colors and shading can also call attention to different types of steps, such as those particularly high on process divergence. Divergence is also communicated when an outgoing arrow from a step splits into two or more arrows that lead to different boxes. Although many representations are acceptable, there must be agreement on the conventions used. They can be given as a key somewhere in the flowchart, and/or described in accompanying text. It is also important to communicate *what* (e.g., information, customer order, customer, and materials) is being tracked.

You can create flowcharts with several programs. Microsoft PowerPoint offers many different formatting choices for flowcharts (see the Flowchart submenu under AutoShapes). The tutorials "Flowcharting in Excel" and "Flowcharting in PowerPoint" in MyOMLab offer other options. Other powerful software packages for flowcharting and drawing diagrams (such as organization charts and decision trees) are SmartDraw (**http://www.smartdraw.com**), Microsoft Visio (**http://www.microsoft.com/office/visio**), and Micrografx (**http://www.micrografx.com**). Often, free downloads are available at such sites on a trial basis.

MyOMLab

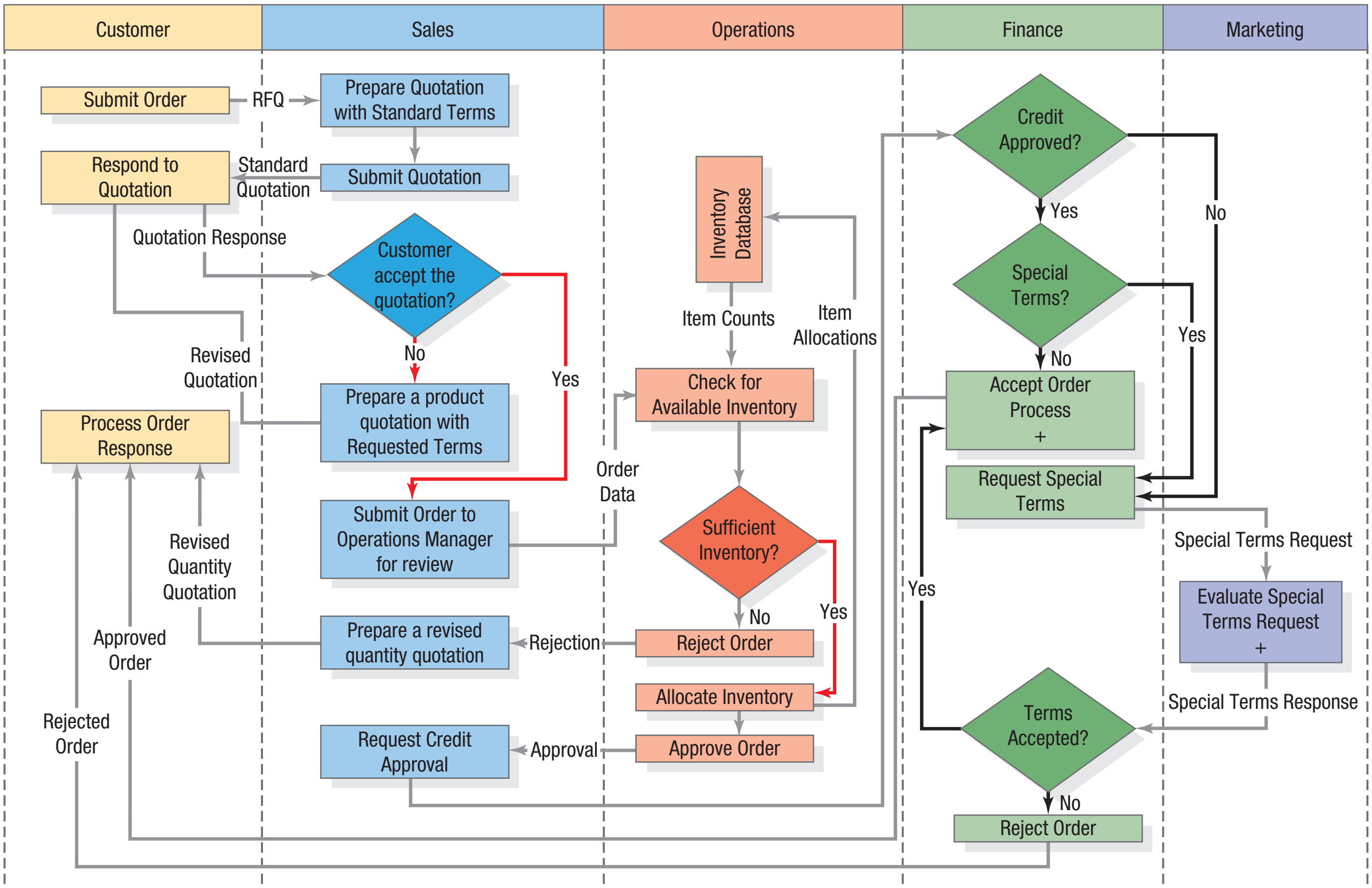
Flowcharts can be created for several levels in the organization. For example, at the strategic level, they could show the core processes and their linkages, as in Figure 1.4 in Chapter 1. At this level, the flowcharts do not have much detail; however, they give a bird's eye view of the overall business. Just identifying a core process is often helpful. However, in this chapter, we focus at the process level, where we get into the details of the process being analyzed. Many steps may have subprocesses nested within them. Rather than representing everything in one flowchart, an overview of the whole process can first be created. Subsequently flowcharts can be developed to flesh out nested processes. This nesting approach often becomes a practical necessity because only so much detail can be shown in any single flowchart.

Swim Lane Flowchart One of the most commonly used forms of a flowchart is the **swim lane flowchart**. It is a visual representation that groups functional areas responsible for different subprocesses into lanes. It is most appropriate when the business process spans several department boundaries, and where parallel lines similar to lanes in a swimming pool separate each department or a functional area. Swim lanes are labeled according to the functional groups they represent and can be arranged either horizontally or vertically.

swim lane flowchart

A visual representation that groups functional areas responsible for different subprocesses into lanes. It is most appropriate when the business process spans several department boundaries.

The swim lane flowchart in Figure 2.7 illustrates the order placement and acceptance process at a manufacturing company. The process starts when an order is generated by a customer and ends when



▲ **FIGURE 2.7**

Swim Lane Flowchart of the Order-Filling Process Showing Handoffs between Departments

Source: D. Kroenke, *Using MIS*, 4th ed., © 2012. Reprinted and electronically reproduced by permission of Pearson Education, Inc., Upper Saddle River, New Jersey.

the order is actually rejected, modified, or approved by the company in consultation with the customer. All functions contributing to this process are included in the flowchart. The columns represent different departments or functional areas, and the steps appear in the department column where they are performed. The customer is also shown as one of the column headings. This approach shows the *handoffs* from one department to another when the outgoing arrow from a step goes to another column. Special dotted-line arrows are one way to show handoffs. Handoffs are points where cross-functional coordination is at particular risk due to the silo mentality. Misunderstandings, backlogs, and errors are more likely at these points.

Figure 2.7 illustrates one other feature. The diamond shape (◊) represents a yes/no decision or outcome, such as the results of an inspection or recognition of different kinds of customer requirements. In Figure 2.7, the diamond represents three yes/no decision points within finance, and one each within sales and operations. These yes/no decision points are more likely to appear when a process is high in divergence.

Swim lane flowcharts allow the process analyst and managers to look at the horizontal organization rather than the vertical organization and departmental boundaries implied by a typical organizational chart. Swim lane flowcharts show how organizations produce their outputs through cross-functional work processes and allow the design team to see all the critical interfaces between functions and departments.

service blueprint

A special flowchart of a service process that shows which steps have high customer contact.

Service Blueprint A **service blueprint** is a special flowchart of a service process that shows which steps have high customer contact. It uses a dotted line of visibility to identify which steps are visible to the customer (and thus are more of a front-office process) and those that are not (back-office process). Of course, visibility is just one aspect of customer contact, and it may not adequately capture how actively the customer is involved or how much personal attention is required. A service blueprint can use colors, shading, or box shapes, instead of the lines of visibility, to show the extent and type of customer contact. Another approach to service blueprinting is to tag each step with a number, and then have an accompanying table that describes in detail the customer contact for each numbered step. There is no one "right way" to create a flow chart or service blueprint.

Work Measurement Techniques

time study

A work measurement method using a trained analyst to perform four basic steps in setting a time standard for a job or process: selecting the work elements (or nested processes) within the process to be studied, timing the elements, determining the sample size, and setting the final standard.

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Process documentation would not be complete without estimates of the average time each step in the process would take. Time estimates are needed not just for process-improvement efforts but for capacity planning, constraint management, performance appraisal, and scheduling. Estimating task times can be as simple as making a reasoned guess, asking a knowledgeable person, or taking notes while observing the process. More extensive studies involve collecting data for several weeks, consulting cost accounting data, or checking data recorded in information systems.

Formal techniques are also available that rely on the judgment of skilled observers: (1) the time study method, (2) the elemental standard data method, (3) the predetermined data method, and (4) work sampling. A fifth method, (5) learning curve analysis, is particularly appropriate when a new product or process is introduced and the time per unit produced has not yet stabilized. The method chosen depends on the purpose of the data, process type (job, batch, or line), and degree of product customization. A more comprehensive treatment of these techniques is provided in MyOMLab Supplement H, "Measuring Output Rates" and MyOMLab Supplement I, "Learning Curve Analysis."

Time Study Method **Time study** uses a trained analyst to perform four basic steps in setting a time standard for a job or process: (1) selecting the work elements (steps in a flowchart or process chart) within the process to be studied, (2) timing the elements, (3) determining the sample size, and (4) setting the final standard. It is essentially the average time observed, adjusted for normal effort and making an allowance for breaks, unavoidable delays, and the like. The analyst records time spent on each element of the process being studied using a stopwatch, and records the time spent on each element for several repetitions. The analyst assigns a performance rating for each element to adjust for normal effort. Some elements may be performed faster or slower than normal, in the analyst's judgment. The allowance is expressed as a proportion or percent of the total *normal* time.

elemental standard data

A database of standards compiled by a firm's analysts for basic elements that they can draw on later to estimate the time required for a particular job, which is most appropriate when products or services are highly customized, job processes prevail, and process divergence is great.

Elemental Standard Data Method Another method is needed when products or services are highly customized, job processes prevail, and process divergence is great. **Elemental standard data** is a database of standards compiled by a firm's analysts for basic elements that they can draw on later to estimate the time required for a particular job. This approach works well when work elements within certain jobs are similar to those in other jobs. Sometimes, the time required for a work element depends on variable characteristics of the jobs, such as the amount of metal to be deposited for a welding process. In such cases, an equation that relates these characteristics to the time required is also stored in the database. Another method, such as time study or past records, still must be used to compile the normal times (before the allowance is added) stored in the database.

EXAMPLE 2.1 Time Study of Watch Assembly Process

A process at a watch assembly plant has been changed. The process is divided into three work elements. A time study has been performed with the following results. The time standard for the process previously was 14.5 minutes. Based on the new time study, should the time standard be revised?

Christopher Bosset/Bloomberg/Getty Images

Workers seen on a watch assembly line at the Jaeger-LeCoultre factory in Le Sentier, Switzerland.

SOLUTION

The new time study had an initial sample of four observations, with the results shown in the following table. The performance rating factor (RF) is shown for each element (to adjust for normal effort), and the allowance for the whole process is 18 percent of the total *normal* time.

	Obs 1	Obs 2	Obs 3	Obs 4	Average (min)	RF	Normal Time
Element 1	2.60	2.34	3.12	2.86	2.730	1.0	2.730
Element 2	4.94	4.78	5.10	4.68	4.875	1.1	5.363
Element 3	2.18	1.98	2.13	2.25	2.135	0.9	1.922
					Total Normal Time = **10.015 minutes**		

The normal time for an element in the table is its average time, multiplied by the RF. The total normal time for the whole process is the sum of the normal times for the three elements, or 10.015 minutes. To get the standard time (ST) for the process, just add in the allowance, or

$$ST = 10.015(1 + 0.18) = \mathbf{11.82} \text{ minutes/watch}$$

DECISION POINT

The time to assemble a watch appears to have decreased considerably. However, based on the precision that management wants, the analyst decided to increase the sample size before setting a new standard. MyOMLab Supplement H, “Measuring Output Rates,” gives more information on determining the number of additional observations needed.

MyOMLab

Predetermined Data Method The **predetermined data method** divides each work element even more, into a series of micromotions that make up the element. The analyst then consults a published database that contains the normal times for the full array of possible micromotions. A process’s normal time can then be calculated as the sum of the times given in the database for the elements performed in the process. This approach makes most sense for highly repetitive processes with little process divergence and line flows. The micromotions (such as reach, move, or apply pressure) are very detailed.

predetermined data method

A database approach that divides each work element into a series of micromotions that make up the element. The analyst then consults a published database that contains the normal times for the full array of possible micromotions.

Work Sampling Method **Work sampling** estimates the proportion of time spent by people or machines on different activities, based on observations randomized over time. Examples of these activities include working on a service or product, doing paperwork, waiting for instructions, waiting for maintenance, or being idle. Such data can then be used to assess a process’s productivity, estimate the allowances needed to set standards for other work measurement methods, and spot areas for process improvement. It is best used when the processes are highly divergent with flexible flows. Figure 2.8 shows the input data and numerical results for one week of observations. It shows an idle time of 23.81 percent for the week and also reports that 237 more observations are needed to achieve the confidence and precision levels required with the input data. How these conclusions are reached is explained in MyOMLab Supplement H, “Measuring Output Rates.”

work sampling

A process that estimates the proportion of time spent by people or machines on different activities, based on observations randomized over time.

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Learning Curve Analysis The time estimation techniques just covered assume that the process is stable. If the process is revised, then just repeat the method for the revised process after it stabilizes. Learning curve analysis, on the other hand, takes into account that learning takes place on an ongoing basis, such as when new products or services are introduced frequently. With instruction and repetition,

(a) Input Data and Numerical Results

Increase Observations | Remove An Observation

Confidence z	1.96	Precision p	0.05

Observation Period	Times Busy	Times Idle	Observations
Monday	6	1	7
Tuesday	5	2	7
Wednesday	7	0	7
Thursday	9	2	11
Friday	5	5	10
Total	32	10	42

(b) Idle Time and Observations Required

Portion of idle times	0.2381
Total observations required	279
Additional observations required	237

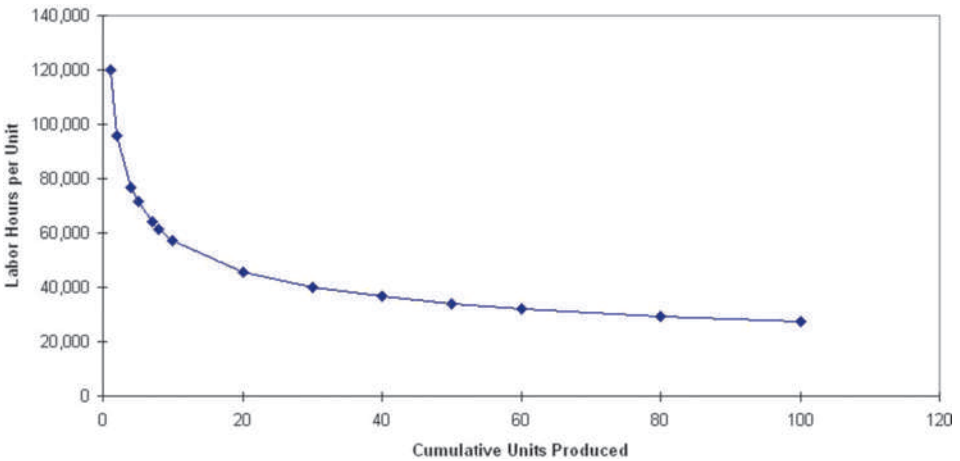
▲ **FIGURE 2.8**
Work Sampling Study of Admission Clerk at Health Clinic Using OM Explorer's *Time Study* Solver.

learning curve

A line that displays the relationship between processing time and the cumulative quantity of a product or service produced.

MyOMLab

workers learn to perform jobs more efficiently, process improvements are identified, and better administration methods are created. These learning effects can be anticipated with a **learning curve**, a line that displays the relationship between processing time and the cumulative quantity of a product or service produced. The time required to produce a unit or create a service decreases as more units or customers are processed. The learning curve for a process depends on the rate of learning and the actual or estimated time for the first unit processed. Figure 2.9 demonstrates the learning curve assuming an 80 percent learning rate, with the first unit taking 120,000 hours and the cumulative average time for the first 10 units produced. The learning rate deals with each *doubling* of the output total. The time for the second unit is 80 percent of the first (or 120,000 × .80 = 96,000 hours), the time for the fourth unit is 80 percent of the second unit (or 96,000 × .80 = 76,800 hours), and so on. Finding the time estimate for a unit that is not an exact doubling (such as the fifth unit), and also the cumulative average time for the first 10 units, is explained in MyOMLab Supplement I, "Learning Curve Analysis."



Time for first unit	120,000
Unit number	10
Time for unit 10	57,172
Cumulative average time per unit	75,784

▲ **FIGURE 2.9**
Learning Curve with 80% Learning Rate Using OM Explorer's *Learning Curves* Solver.

Process Charts

process chart

An organized way of documenting all the activities performed by a person or group of people, at a workstation, with a customer, or on materials.

A **process chart** is an organized way of documenting all the activities performed by a person or group of people at a workstation, with a customer, or working with certain materials. It analyzes a process using a table, and provides information about each step in the process. In contrast to flowcharts, swim lane flowcharts, and service blueprints, it requires the time estimates (see work measurement techniques covered in the last section). Often it is used to drill down to the job level for an individual person, a team, or a focused nested process. It can have many formats. Here, we group the type of activities for a typical process into five categories:

- *Operation*. Changes, creates, or adds something. Drilling a hole or serving a customer are examples of operations.
- *Transportation*. Moves the study's subject from one place to another (sometimes called *materials handling*). The subject can be a person, a material, a tool, or a piece of equipment. A customer walking from one end of a counter to the other, a crane hoisting a steel beam to a location, and a conveyor carrying a partially completed product from one workstation to the next are examples of transportation. It could also be the shipment of a finished product to the customer or a warehouse.

- *Inspection*. Checks or verifies something but does not change it. Getting customer feedback, checking for blemishes on a surface, weighing a product, and taking a temperature reading are examples of inspections.
- *Delay*. Occurs when the subject is held up awaiting further action. Time spent waiting for a server; time spent waiting for materials or equipment; cleanup time; and time that workers, machines, or workstations are idle because they have no work to complete are examples of delays.
- *Storage*. Occurs when something is put away until a later time. Supplies unloaded and placed in a storeroom as inventory, equipment put away after use, and papers put in a file cabinet are examples of storage.

Depending on the situation, other categories can be used. For example, subcontracting for outside services might be a category, temporary storage and permanent storage, or environmental waste might be three separate categories. Choosing the right category for each activity requires taking the perspective of the subject charted. A delay for the equipment could be inspection or transportation for the operator.

To complete a chart for a new process, the analyst must identify each step performed. If the process is an existing one, the analyst can actually observe the steps and categorize each step according to the subject being studied. The analyst then records the distance traveled and the time taken to perform each step. After recording all the activities and steps, the analyst summarizes the steps, times, and distances data. Figure 2.10 shows a process chart prepared using OM Explorer's *Process Chart* Solver. It is for a patient with a twisted ankle being treated at a hospital. The process begins at the entrance and ends with the patient exiting after picking up the prescription.

After a process is charted, the analyst sometimes estimates the annual cost of the entire process. It becomes a benchmark against which other methods for performing the process can be evaluated. Annual labor cost can be estimated by finding the product of (1) time in hours to perform the process each time, (2) variable costs per hour, and (3) number of times the process is performed each year, or

$$\begin{matrix}\text{Annual}\\ \text{labor cost}\end{matrix} = \begin{pmatrix}\text{Time to perform}\\ \text{the process in hours}\end{pmatrix}\begin{pmatrix}\text{Variable costs}\\ \text{per hour}\end{pmatrix}\begin{pmatrix}\text{Number of times process}\\ \text{is performed per year}\end{pmatrix}$$

MyOMLab
Tutor 2.2 in MyOMLab provides a new example to practice creating process charts.

Process:	Emergency room admission
Subject:	Ankle injury patient
Beginning:	Enter emergency room
Ending:	Leave hospital

Insert Step

Append Step

Remove Step

Summary

Activity		Number of Steps	Time (min)	Distance (ft)
Operation	●	5	23.00	
Transport	➡	9	11.00	815
Inspect	■	2	8.00	
Delay	◗	3	8.00	
Store	▼	—	—	

Step No.	Time (min)	Distance (ft)	●	➡	■	◗	▼	Step Description
1	0.50	15.0		X				Enter emergency room, approach patient window
2	10.00		X					Sit down and fill out patient history
3	0.75	40.0		X				Nurse escorts patient to ER triage room
4	3.00				X			Nurse inspects injury
5	0.75	40.0		X				Return to waiting room
6	1.00					X		Wait for available bed
7	1.00	60.0		X				Go to ER bed
8	4.00					X		Wait for doctor
9	5.00				X			Doctor inspects injury and questions patient
10	2.00	200.0		X				Nurse takes patient to radiology
11	3.00		X					Technician x-rays patient
12	2.00	200.0		X				Return to bed in ER
13	3.00					X		Wait for doctor to return
14	2.00		X					Doctor provides diagnosis and advice
15	1.00	60.0		X				Return to emergency entrance area
16	4.00		X					Check out
17	2.00	180.0		X				Walk to pharmacy
18	4.00		X					Pick up prescription
19	1.00	20.0		X				Leave the building

FIGURE 2.10
Process Chart for Emergency Room Admission

MyOMLab Animation

For example, if the average time to serve a customer is 4 hours, the variable cost is \$25 per hour, and 40 customers are served per year, then the labor cost is \$4,000 per year (or 4 hrs/customer × \$25/hr × 40 customers/yr).

In the case of the patient in Figure 2.10, this conversion would not be necessary, with total patient time being sufficient. What is being tracked is the patient's time, not the time and costs of the service providers.

You can design your own process chart spreadsheets to bring out issues that are particularly important for the process you are analyzing, such as categories for customer contact, process divergence, and the like. You can also track performance measures other than time and distance traveled, such as error rates. In addition, you can also create a different version of the process chart spreadsheet that examines processes much as done with flowcharts, except now in the form of a table. The columns that categorize the activity type could be replaced by one or more columns reporting different metrics of interest, rather than trying to fit them into a flowchart. Although it might not look as elegant, it could be just as informative—and easier to create.

Andresr/Shutterstock.com

The leader of a design team presents several charts that document a process in their office that they are analyzing. He is identifying several areas of substandard performance across a range of different metrics. The next step will be to redesign the process. The flipchart on the right will be quite useful in generating rapid fire ideas from the team on how the process might be improved.

Data Analysis Tools

Metrics and performance information complete the documentation of a process. The specific metrics analysts choose depends on the process being analyzed and on the competitive priorities. Good starting points are the per-unit processing time and cost at each step, and the time elapsed from beginning to end of the process. Capacity utilization, environmental issues, and customer (or job) waiting times reveal where in the process delays are most likely to occur. Customer satisfaction measures, error rates, and scrap rates identify possible quality problems. We introduce many such metrics in subsequent chapters. Only when these subsequent chapters are understood do we really complete our discussion of process analysis.

Metrics can be displayed in various ways. Sometimes, they can be added directly on the flowchart or process chart. When the number of metrics gets unwieldy, another approach is to create a supporting table for the chart. Its rows are the steps in the flowchart, swim lane flowchart, service blueprint, or process chart. The columns are the current performance, goals, and performance gaps for various metrics. Various tools are available to help you understand the causes of these performance gaps and problems[1]. Here we present six tools: (1) checklists, (2) histograms and bar charts, (3) Pareto charts, (4) scatter diagrams, (5) cause-and-effect diagrams, and (6) graphs. Many of them were developed initially to analyze quality issues, but they apply equally well to process analysis in general.

checklist

A form used to record the frequency of occurrence of certain process failures.

process failure

Any performance shortfall, such as error, delay, environmental waste, rework, and the like.

histogram

A summarization of data measured on a continuous scale, showing the frequency distribution of some process failure (in statistical terms, the central tendency and dispersion of the data).

bar chart

A series of bars representing the frequency of occurrence of data characteristics measured on a yes-or-no basis.

Checklists Data collection through the use of a checklist is often the first step in the analysis of a metric. A **checklist** is a form used to record the frequency of occurrence of certain process failures. A **process failure** is any performance shortfall, such as error, delay, environmental waste, rework, and the like. The characteristics may be measurable on a continuous scale (e.g., weight, customer satisfaction on a 1 to 7 scale, unit cost, scrap loss percentage, time, or length) or on a yes-or-no basis (e.g., customer complaint, posting error, paint discoloration, or inattentive servers).

Histograms and Bar Charts Data from a checklist often can be presented succinctly and clearly with histograms or bar charts. A **histogram** summarizes data measured on a continuous scale, showing the frequency distribution of some process failure (in statistical terms, the central tendency and dispersion of the data). Often the mean of the data is indicated on the histogram. A **bar chart** (see Figure 2.11) is a series of bars representing the frequency of occurrence of data characteristics measured on a yes-or-no basis. The bar height indicates the number of times a particular process failure was observed.

[1]Several of these tools, particularly Pareto charts and cause-and-effect diagrams, are closely affiliated with Chapter 3, "Managing Quality." We introduce them here because they apply to process failures in general and not just to quality rejects.

Pareto Charts When managers discover several process problems that need to be addressed, they have to decide which should be attacked first. Vilfredo Pareto, a nineteenth-century Italian scientist whose statistical work focused on inequalities in data, proposed that most of an "activity" is caused by relatively few of its factors. In a restaurant quality problem, the activity could be customer complaints and the factor could be "discourteous server." For a manufacturer, the activity could be product defects and the factor could be "missing part." Pareto's concept, called the 80–20 rule, is that 80 percent of the activity is caused by 20 percent of the factors. By concentrating on the 20 percent of the factors (the "vital few"), managers can attack 80 percent of the process failure problems. Of course, the exact percentages vary with each situation, but inevitably relatively few factors cause most of the performance shortfalls.

The few vital factors can be identified with a **Pareto chart**, a bar chart on which the factors are plotted along the horizontal axis in decreasing order of frequency (see Figure 2.12). The chart has two vertical axes, the one on the left showing frequency (as in a histogram) and the one on the right showing the cumulative percentage of frequency. The cumulative frequency curve identifies the few vital factors that warrant immediate managerial attention.

Pareto chart
A bar chart on which factors are plotted along the horizontal axis in decreasing order of frequency.

EXAMPLE 2.2 Pareto Chart for a Restaurant

The manager of a neighborhood restaurant is concerned about the lower numbers of customers patronizing his eatery. Complaints have been rising, and he would like to find out what issues to address and present the findings in a way his employees can understand.

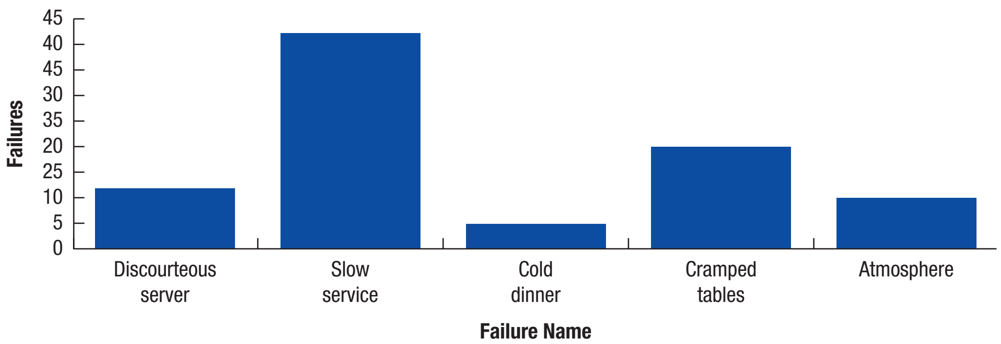
MyOMLab
Active Model 2.1 in MyOMLab provides additional insights on this Pareto chart example and its extensions.

MyOMLab
Tutor 2.3 in MyOMLab provides a new example on creating Pareto charts.

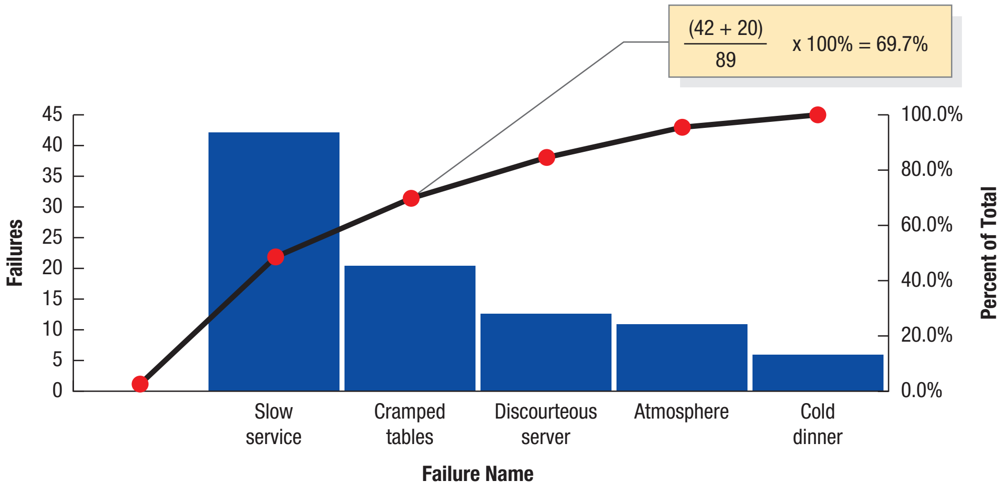
SOLUTION

The manager surveyed his customers over several weeks and collected the following data:

Complaint	Frequency
Discourteous server	12
Slow service	42
Cold dinner	5
Cramped tables	20
Atmosphere	10



◀ **FIGURE 2.11**
Bar Chart



◀ **FIGURE 2.12**
Pareto Chart

Figure 2.11 is a bar chart and Figure 2.12 is a Pareto chart, both created with OM Explorer's *Bar, Pareto, and Line Charts* Solver. They present the data in a way that shows which complaints are more prevalent (the vital few). You can reformat these charts for any yes-or-no metrics by unprotecting the spreadsheet and then making your revisions. Another approach is to create your own spreadsheets from scratch. More advanced software with point-and-click interfaces include Minitab (**http://www.minitab.com/index.htm**), SAS (**http://www.sas.com/rnd/app/qc.html**), and Microsoft Visio (**http://www.microsoft.com/office/visio**).

DECISION POINT

It was clear to the manager (and all employees) which complaints, if rectified, would cover most of the process failure problems in the restaurant. First, slow service will be addressed by training the existing staff, adding another server, and improving the food preparation process. Removing some decorative furniture from the dining area and spacing the tables better will solve the problem with cramped tables. The Pareto chart shows that these two problems, if rectified, will account for almost 70 percent of the complaints.

Scatter Diagrams Sometimes managers suspect that a certain factor is causing a particular process failure. A **scatter diagram**, which is a plot of two variables showing whether they are related, can be used to verify or negate the suspicion. Each point on the scatter diagram represents one data observation. For example, the manager of a castings shop may suspect that casting defects are a function of the diameter of the casting. A scatter diagram could be constructed by plotting the number of defective castings found for each diameter of casting produced. After the diagram is completed, any relationship between diameter and number of process failures will be clear.

scatter diagram

A plot of two variables showing whether they are related.

Cause-and-Effect Diagrams An important aspect of process analysis is linking each metric to the inputs, methods, and process steps that build a particular attribute into the service or product. One way to identify a design problem is to develop a **cause-and-effect diagram** that relates a key performance problem to its potential causes. First developed by Kaoru Ishikawa, the diagram helps management trace disconnects directly to the operations involved. Processes that have no bearing on a particular problem are not shown on the diagram.

cause-and-effect diagram

A diagram that relates a key performance problem to its potential causes.

The cause-and-effect diagram sometimes is called a *fishbone diagram*. The main performance gap is labeled as the fish's "head," the major categories of potential causes as structural "bones," and the likely specific causes as "ribs." When constructing and using a cause-and-effect diagram, an analyst identifies all the major categories of potential causes for the problem. These might be personnel, machines, materials, and processes. For each major category, the analyst lists all the likely causes of the performance gap. Under personnel might be listed "lack of training," "poor communication," and "absenteeism." Creative thinking helps the analyst identify and properly classify all suspected causes. The analyst then systematically investigates the causes listed on the diagram for each major category, updating the chart as new causes become apparent. The process of constructing a cause-and-effect diagram calls management and worker attention to the primary factors affecting process failures. Example 2.3 demonstrates the use of a cause-and-effect diagram by a firm manufacturing air conditioners.

EXAMPLE 2.3 Analysis of Inadequate Production of Headers

A process improvement team is working to improve the production output at the Johnson Manufacturing plant's Header Cell that manufactures a key component, headers, used in commercial air conditioners. A header is part of the circulatory system of a commercial air conditioner that moves coolant between various components such as the evaporator coil and the condenser coil. Currently, the header production cell is scheduled separately from the main work in the plant. Often, individual headers are not sequenced to match the product they go into on the final assembly line in a timely fashion, and so the product can sit in queue waiting for a header.

SOLUTION

As a first step, the team conducted extensive on-site observations across the six processing steps within the cell, followed by the transport of the finished header to the air conditioner assembly area for installation into an air conditioner unit. The six processing steps included:

1. Cut copper pipes to the appropriate length.
2. Punch vent and stub holes into the copper log.
3. Weld a steel supply valve onto the top of the copper log.

4. Braze end caps and vent plugs to the copper log.
5. Braze stub tubes into each stub hole in the copper log.
6. Add plastic end caps to protect the newly created header.

To analyze all the possible causes of the problem, the team constructed a cause-and-effect diagram, shown in Figure 2.13. The main problem, inadequate header production, is the head of the diagram. The team brainstormed all possible causes, and together they identified several major categories: management, manpower, method, measurement, machine, and materials, or the 6 M's. Several suspected causes were identified for each major category.

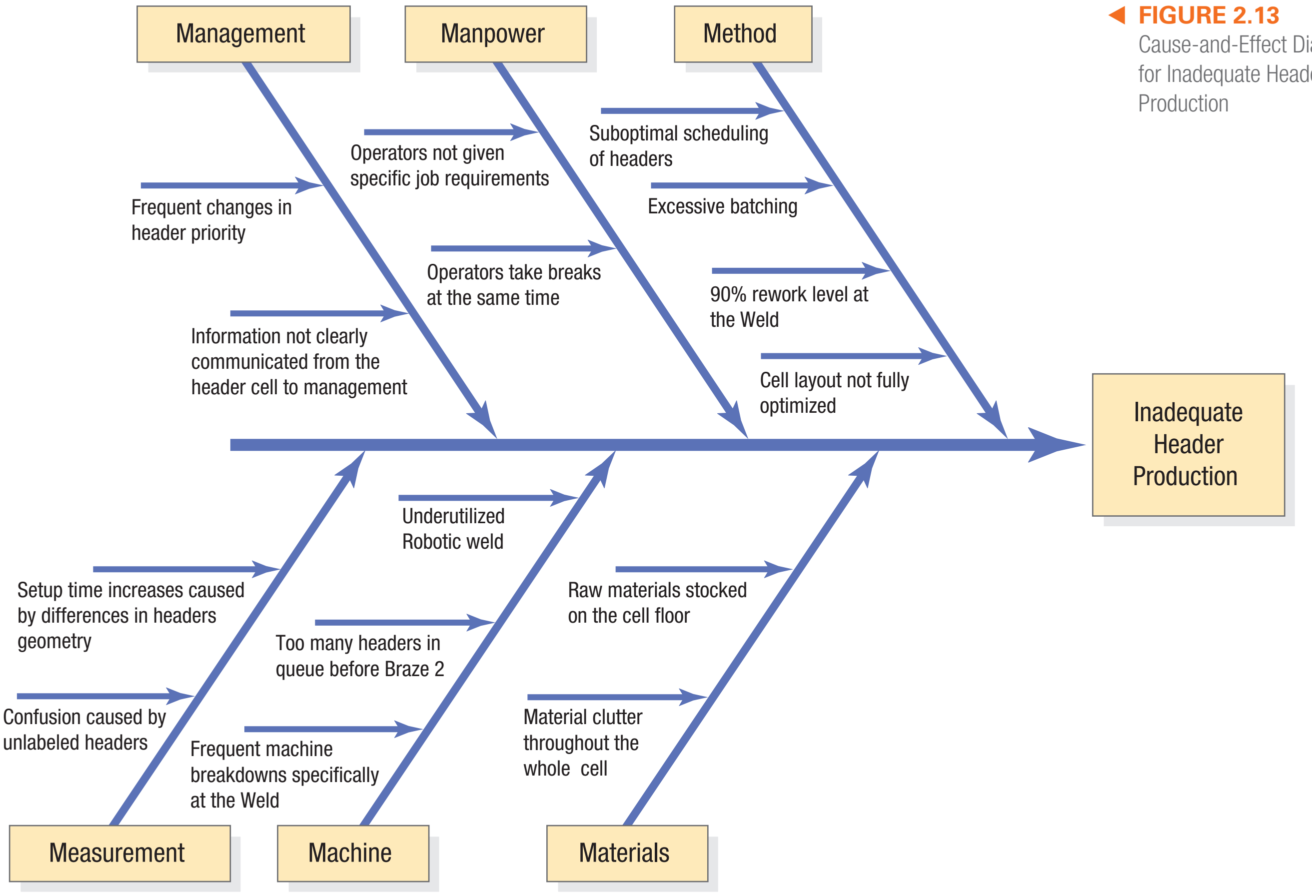


FIGURE 2.13 Cause-and-Effect Diagram for Inadequate Header Production

DECISION POINT

The improvement team noted several immediate issues that were slowing down production of headers. These issues included operators batching individual jobs (method branch) into groups to save walking time, which was further exasperated by the availability of raw materials stocked on the shop floor (materials branch) and the lack of specific job requirement (management branch). Further, there were many instances of individual tasks not being done correctly, and thus having to be redone; such as the 90 percent rework rate at weld (method branch). The next step in this process improvement was to eliminate the raw material on the floor, improve quality at the weld machine, and move each header individually using a header-specific cart.

Graphs Visualizing data in user-friendly ways can greatly enhance process analysis. **Graphs** represent data in a variety of pictorial formats, such as line charts and pie charts. *Line charts* represent data sequentially with data points connected by line segments to highlight trends in the data. Line charts are used in control charts (see Chapter 3, "Managing Quality") and forecasting (see Chapter 8, "Forecasting Demand"). Pie charts represent process factors as slices of a pie; the size of each slice is in proportion to the number of occurrences of the factor. Pie charts are useful for showing data from *a group of factors* that can be represented as percentages totaling 100 percent.

graphs
Representations of data in a variety of pictorial forms, such as line charts and pie charts.

Each of the tools for improving quality may be used independently, but their power is greatest when they are used together. In solving a process-related problem, managers often must act as detectives, sifting data to clarify the issues involved and deducing the causes. We call this process *data snooping*. Example 2.4 demonstrates how the tools for improving quality can be used for data snooping.

EXAMPLE 2.4 Identifying Causes of Poor Headliner Process Failures

The Wellington Fiber Board Company produces headliners, the fiberglass components that form the inner roof of passenger cars. Management wanted to identify which process failures were most prevalent and to find the cause.

SOLUTION

Figure 2.14 shows the sequential application of several tools for improving quality.

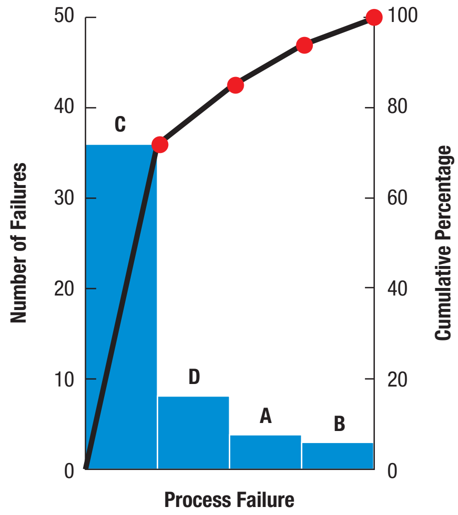
FIGURE 2.14
Application of the Tools for Improving Quality

Step 1. Checklist

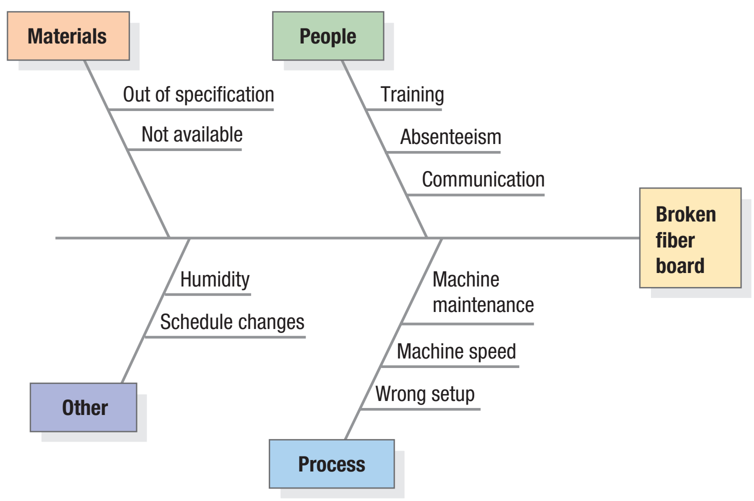
Headliner failures

Process failure	Tally	Total
A. Tears in fabric	IIII	4
B. Discolored fabric	III	3
C. Broken fiber board	卌 卌 卌 卌 卌 卌 卌 I	36
D. Ragged edges	卌 II	7
		Total 50

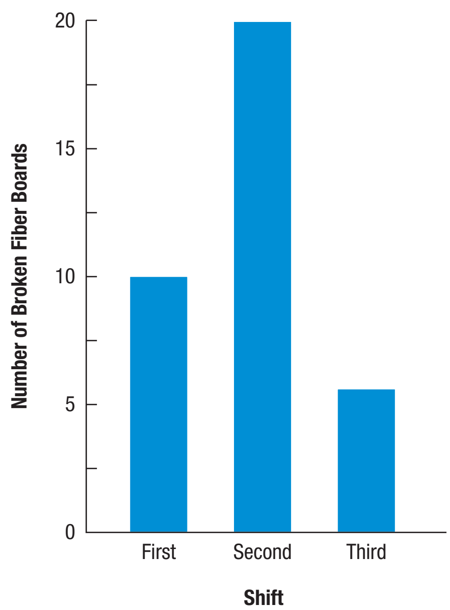
Step 2. Pareto Chart



Step 3. Cause-and-Effect Diagram



Step 4. Bar Chart



Step 1. A checklist of different types of process failures was constructed from last month's production records.

Step 2. A Pareto chart prepared from the checklist data indicated that broken fiber board accounted for 72 percent of the process failures.

Step 3. A cause-and-effect diagram for broken fiber board identified several potential causes for the problem. The one strongly suspected by the manager was employee training.

Step 4. The manager reorganized the production reports into a bar chart according to shift because the personnel on the three shifts had varied amounts of experience.

DECISION POINT

The bar chart indicated that the second shift, with the least experienced workforce, had most of the process failures. Further investigation revealed that workers were not using proper procedures for stacking the fiber boards after the press operation, which caused cracking and chipping. The manager set up additional training sessions focused on board handling. Although the second shift was not responsible for all the process failures, finding the source of many of the failures enabled the manager to improve the performance of her operations.

A simulation model goes one step further than static data analysis tools, because it can show how the process dynamically changes over time. **Process simulation** is the act of reproducing the behavior of a process, using a model that describes each step. Once the process is modeled, the analyst can make changes in the model to measure the impact on certain metrics, such as response time, waiting lines, resource utilization, and the like. To learn more about how simulation works, see MyOMLab Supplement E, "Simulation."

process simulation

The act of reproducing the behavior of a process, using a model that describes each step.

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Redesigning and Managing Process Improvements

A doctor pinpoints an illness after a thorough examination of the patient, and then the doctor recommends treatments based on the diagnosis; so it is with processes. After a process is documented, metrics data are collected, and disconnects are identified, the process analyst or design team puts together a set of changes that will make the process better. At this step, people directly involved in the process are brought in to get their ideas and inputs.

brainstorming

Letting a group of people, knowledgeable about the process, propose ideas for change by saying whatever comes to mind.

Questioning and Brainstorming

Sometimes, ideas for reengineering or improving a process become apparent after documenting the process and carefully examining the areas of substandard performance, handoffs between departments, and steps where customer contact is high. Example 2.4 illustrated how such documentation pointed to a better way of handling the fiber boards through better training. In other cases, the better solution is less evident. Ideas can be uncovered (because there is always a better way) by asking six questions about each step in the process, and a final series of questions about the process as a whole:

1. *What* is being done?
2. *When* is it being done?
3. *Who* is doing it?
4. *Where* is it being done?
5. *How* is it being done?
6. *How* well does it do on the various metrics of importance?

Answers to these questions are challenged by asking still another series of questions. *Why* is the process even being done? *Why* is it being done where it is being done? *Why* is it being done when it is being done?

Creativity can also be stimulated by **brainstorming**, letting a group of people knowledgeable about the process propose ideas for change by saying whatever comes to mind. A facilitator records the ideas on a flipchart, so that all can see. Participants are discouraged from evaluating any of the ideas generated during the session. The purpose is

Chad Baker/Jasone Reed/Ryan McVay/Getty Images

Baptist Memorial Hospital in Memphis, Tennessee, holds "huddle meetings" at least three times a day seeking out process improvements. The meetings bring together the hospital's house supervisor, housekeeping supervisor, and key nurses. Improvements have been dramatic. In 2011, the hospital was ranked in the top 5 percent nationally for emergency medicine.

to encourage creativity and to get as many ideas as possible, no matter how far-fetched the ideas may seem. The participants of a brainstorming session need not be limited to the design team as long as they have seen or heard the process documentation. A growing number of big companies are taking advantage of the Internet and specially designed software to run brainstorming sessions that allow people at far-flung locations to "meet" online and hash out solutions to particular problems. The technology lets employees see, and build on, one another's ideas, so that one person's seed of a notion can grow into a practical plan.

After the brainstorming session is over, the design team moves into the "get real" phase: They evaluate the different ideas. The team identifies the changes that give the best payoffs for process redesign. The redesign could involve issues of capacity, technology, or even location, all of which are discussed in more detail in the following chapters.

MyOMLab

The redesigned process is documented once again, this time as the "after" view of the process. Expected payoffs are carefully estimated, along with risks. For changes involving investments, the time value of money must be considered (see MyOMLab Supplement F, "Financial Analysis"). The impact on people (skills, degree of change, training requirements, and resistance to change) must also be factored into the evaluation of the new design.

Benchmarking

benchmarking

A systematic procedure that measures a firm's processes, services, and products against those of industry leaders.

Benchmarking can be another valuable source for process redesign. **Benchmarking** is a systematic procedure that measures a firm's processes, services, and products against those of industry leaders. Companies use benchmarking to better understand how outstanding companies do things so that they can improve their own processes.

Benchmarking focuses on setting quantitative goals for improvement. *Competitive* benchmarking is based on comparisons with a direct industry competitor. *Functional* benchmarking compares areas such as administration, customer service, and sales operations with those of outstanding firms in any industry. For instance, Xerox benchmarked its distribution function against L.L. Bean's because L.L. Bean is renowned as a leading retailer in distribution efficiency and customer service. *Internal* benchmarking involves using an organizational unit with superior performance as the benchmark for other units. This form of benchmarking can be advantageous for firms that have several business units or divisions. All forms of benchmarking are best applied in situations where you are looking for a long-term program of continuous improvement.

Typical measures used in benchmarking include cost per unit, service upsets (breakdowns) per customer, processing time per unit, customer retention rates, revenue per unit, return on investment, and customer satisfaction levels.

Collecting benchmarking data can sometimes be a challenge. Internal benchmarking data is surely the most accessible. One way of benchmarking is always available—tracking the performance of a process over time. Functional benchmarking data are often collected by professional associations or consulting firms. Several corporations and government organizations have agreed to share and standardize performance benchmarks. The American Productivity and Quality Center, a nonprofit organization, created thousands of measures, as Figure 2.15 illustrates. A full range of metrics can be explored at **http://www.apqc.org**. Another source is the Supply Chain Council, which has defined key metrics in its Supply Chain Operations Reference (SCOR) model (See Chapter 14, "Integrating the Supply Chain.").

Implementing

Implementing a beautifully redesigned process is only the beginning to continually monitoring and improving processes. Metrics goals must be continually evaluated and reset to fit changing requirements. Avoid the following seven mistakes when managing processes:[2]

1. *Not Connecting with Strategic Issues.* Is particular attention being paid to core processes, competitive priorities, impact of customer contact and volume, and strategic fit during process analysis?
2. *Not Involving the Right People in the Right Way.* Does process analysis closely involve the people performing the process, or those closely connected to it as internal customers and suppliers?
3. *Not Giving the Design Teams and Process Analysts a Clear Charter, and then Holding Them Accountable.* Does management set expectations for change and maintain pressure for results? Does it allow paralysis in process-improvement efforts by requiring excessive analysis?
4. *Not Being Satisfied Unless Fundamental "Reengineering" Changes Are Made.* Is the radical change from process reengineering the expectation? If so, the cumulative effect of many small improvements that could be made incrementally could be lost. Process management efforts should not be

[2]Geary A. Rummler and Alan P. Brache, *Improving Performance*, 2nd ed. (San Francisco: Jossey-Bass, 1995), pp. 126–133.

FIGURE 2.15
Illustrative Benchmarking Metrics by Type of Process

Customer Relationship Process

- Total cost of "enter, process, and track orders" per $1,000 revenue
- System costs of process per $100,000 revenue
- Value of sales order line item not fulfilled due to stockouts, as percentage of revenue
- Percentage of finished goods sales value that is returned
- Average time from sales order receipt until manufacturing or logistics is notified
- Average time in direct contact with customer per sales order line item
- Energy consumed in transporting product
- Total distance traveled for products
- Green house gas emissions

Order Fulfillment Process

- Value of plant shipments per employee
- Finished goods inventory turnover
- Reject rate as percentage of total orders processed
- Percentage of orders returned by customers due to quality problems
- Standard customer lead time from order entry to shipment
- Percentage of orders shipped on time
- Use of non-renewable energy sources
- Use of toxic ingredients
- Safe and healthy work environment

New Service/Product Development Process

- Percentage of sales due to services/products launched last year
- Cost of "generate new services/products" process per $1,000 revenue
- Ratio of projects entering the process to projects completing the process
- Time to market for existing service/product improvement project
- Time to market for new service/product project
- Time to profitability for existing service/product improvement project

Supplier Relationship Process

- Cost of "select suppliers and develop/maintain contracts" process per $1,000 revenue
- Number of employees per $1,000 of purchases
- Percentage of purchase orders approved electronically
- Average time to place a purchase order
- Total number of active vendors per $1,000 of purchases
- Percentage of value of purchased material that is supplier certified
- Amount of toxic chemicals used in supplies production process
- Energy consumed in transporting raw materials and parts
- Total distance traveled for raw materials and parts
- Green house gas emissions
- Supplier's use of toxic chemicals in production process
- Percentage of child labor used by supplier

Support Process

- Systems cost of finance function per $1,000 revenue
- Percentage of finance staff devoted to internal audit
- Total cost of payroll processes per $1,000 revenue
- Number of accepted jobs as percentage of job offers
- Total cost of "source, recruit, and select" process per $1,000 revenue
- Average employee turnover rate

limited to downsizing or to reorganization only, even though jobs may be eliminated or the structure changed. It should not be limited to big technological innovation projects, even though technological change occurs often.

5. *Not Considering the Impact on People.* Are the changes aligned with the attitudes and skills of the people who must implement the redesigned process? It is crucial to understand and deal with the *people side* of process changes.

6. *Not Giving Attention to Implementation.* Are processes redesigned but never implemented? A great job of flowcharting and benchmarking is of only academic interest if the proposed changes are not implemented. Sound project management practices are required.

7. *Not Creating an Infrastructure for Continuous Process Improvement.* Is a measurement system in place to monitor key metrics over time? Is anyone checking to see whether anticipated benefits of a redesigned process are actually being realized?

Failure to manage processes is failure to manage the business. Managers must make sure that their organization spots new performance gaps in the continual search for process improvements. Process redesign efforts need to be part of periodic reviews and even annual plans. Measurement is the particular focus of the next chapter. It covers how a performance tracking system is the basis for feedback and improvement efforts. The essence of a learning organization is the intelligent use of such feedback.

LEARNING GOALS IN REVIEW

Learning Goal	Guidelines for Review	MyOMLab Resources
1 Understand the process structure in services and how to position a service process on the customer-contact matrix	The section "Process Structure in Services," pp. 72–74, shows at the process level the key contextual variables associated with service processes and how they relate to each other. There is a key figure in this section: Figure 2.2 brings together three key elements: (1) the degree of customer contact, (2) customization, and (3) process characteristics. It shows how the degree of customer contact and customization are linked with process divergence and line flows.	
2 Understand the process structure in manufacturing and how to position a manufacturing process on the product-process matrix.	See the section "Process Structure in Manufacturing," pp. 74–76, which focuses on the manufacturing processes. Figure 2.3 brings together three key elements: (1) volume, (2) product customization, and (3) process characteristics. The key drivers are customization and volume, which are linked with line flows and the extent of repetitive work. See the video "Manufacturing Process Structure Choices" to understand how SOME BURROS Mexican Restaurant, WT Graphix Custom Embroidery and Silk Screening, and Crayola make trade-offs between customization and volume in designing their processes.	**Video:** Manufacturing Process Structure Choices
3 Explain the major process strategy decisions and their implications for operations.	"Process Strategy Decisions," pp. 76–80, explains three major process strategy decisions shown in Figure 2.1. Apart from process structure, these include customer involvement, resource flexibility, and capital intensity. Note that customer involvement has advantages and disadvantages, resource flexibility applies to both workforce and equipment, and economies of scope in certain situations can break the inverse relationship between resource flexibility and capital intensity.	**OM Explorer Tutor:** Break-Even for Equipment Selection **POM for Windows:** Break-Even Analysis
4 Discuss how process decisions should strategically fit together.	See "Strategic Fit," pp. 80–82, for a detailed discussion of how managers should understand how the four major process decisions tie together in service and manufacturing firms, so as to spot ways of improving poorly designed processes.	
5 Compare and contrast the two commonly used strategies for change, and understand a systematic way to analyze and improve processes.	The section "Strategies for Change," pp. 82–84, explains two different but complementary philosophies for process design and change: (1) process reengineering and (2) process improvement. The Six Sigma DMAIC model for process improvement then shows a systematic way in which processes can be defined, measured, analyzed, improved, and controlled.	
6 Discuss how to document and evaluate processes.	The section "Documenting and Evaluating the Process," pp. 84–95, discusses three major techniques for effectively documenting and evaluating processes including (1) flowcharts, (2) work measurement techniques, and (3) process charts. Review the Solved Problems for examples of flowchart, process chart, and Pareto chart construction. The time study method, elemental standard data method, predetermined data method, work sampling method, and learning curve analysis are briefly described in the "Work Measurement Techniques" section, pp. 86–88. Pareto charts and cause-and-effect diagrams help you to understand the causes of performance gaps.	**Video:** Process Analysis at Starwood **Cases:** Custom Molds, Inc.; José's Authentic Mexican Restaurant **OM Explorer Solvers:** Learning Curve Analysis; Measuring Output Rates; Process Charts; Pareto Charts **OM Explorer Tutors:** Process Charts; Pareto Charts **POM for Windows:** Learning Curve Analysis; Measuring Output Rates **Supplement I:** Learning Curve Analysis
7 Identify the commonly used approaches for effectively redesigning and managing processes.	The section "Redesigning and Managing Process Improvements," pp. 95–98, discusses how the process analyst puts together a set of changes that will make the process better. Then seven mistakes to avoid when managing processes are discussed at the end. There must be a continual search for process improvements.	

Key Terms

assemble-to-order strategy 76
automation 79
back office 74
bar chart 90
batch process 75
benchmarking 96
Black Belt 84
brainstorming 95
capital intensity 72
cause-and-effect diagram 92
checklist 90
continuous-flow process 75
customer contact 72
customer involvement 71
design-to-order strategy 76
economies of scope 80
elemental standard data 86
fixed automation 79
flexible (or programmable) automation 79
flexible flow 73
flexible workforce 78
flowchart 84
focused factories 82
front office 73
graphs 93
Green Belt 84
histogram 90
hybrid office 73
industrial robot 79
job process 75
layout 71
learning curve 88
line flow 73
line process 75
make-to-order strategy 76
make-to-stock strategy 76
mass customization 76
mass production 76
Master Black Belt 84
metrics 83
Pareto chart 91
plants within plants (PWPs) 81
postponement 76
predetermined data method 87
process analysis 71
process chart 88
process choice 75
process divergence 73
process failure 90
process improvement 83
process simulation 95
process strategy 71
process structure 71
reengineering 82
resource flexibility 71
scatter diagram 92
service blueprint 86
swim lane flowchart 85
time study 86
work sampling 87

Solved Problem 1

MyOMLab Video

Create a flowchart for the following telephone-ordering process at a retail chain that specializes in selling books and music CDs. It provides an ordering system via the telephone to its time-sensitive customers besides its regular store sales.

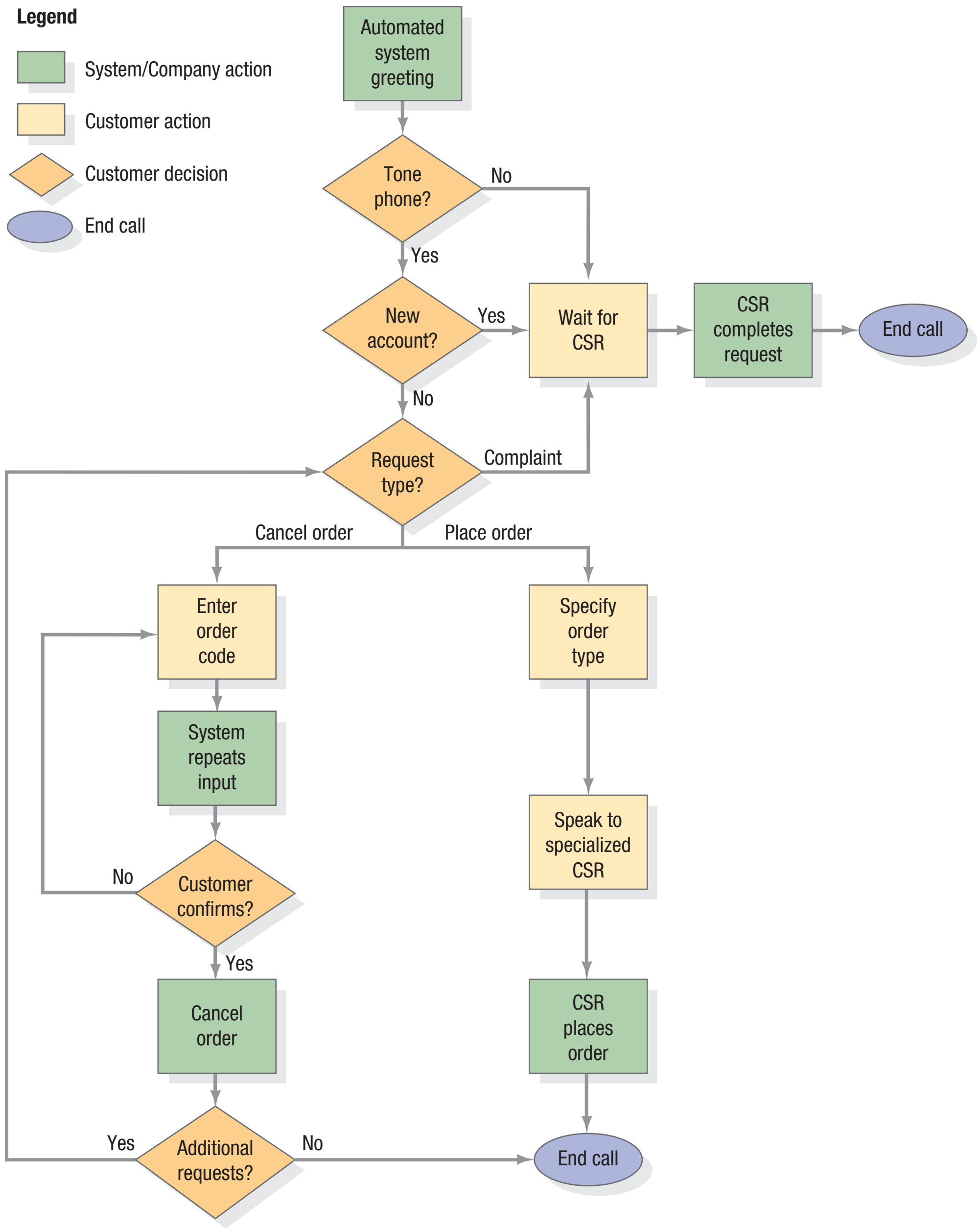
First, the automated system greets customers and identifies whether they have a tone or pulse phone. Customers choose 1 if they have a tone phone; otherwise, they wait for the first available service representative to process their request. If customers have a tone phone, they complete their request by choosing options on the phone. First, the system checks to see whether customers have an existing account. Customers choose 1 if they have an existing account or choose 2 if they want to open a new account. Customers wait for the service representative to open a new account if they choose 2.

Next, customers choose between the options of making an order, canceling an order, or talking to a customer representative for questions and/or complaints. If customers choose to make an order, then they specify the order type as a book or a music CD, and a specialized customer representative for books or music CDs picks up the phone to get the order details. If customers choose to cancel an order, then they wait for the automated response. By entering the order code via phone, customers can cancel the order. The automated system says the name of the ordered item and asks for the confirmation of the customer. If the customer validates the cancellation of the order, then the system cancels the order; otherwise, the system asks the customer to input the order code again. After responding to the request, the system asks whether the customer has additional requests; if not, the process terminates.

SOLUTION

Figure 2.16 shows the flowchart.

FIGURE 2.16 ▶
Flowchart of Telephone Ordering Process



Solved Problem 2

An automobile service is having difficulty providing oil changes in the 29 minutes or less mentioned in its advertising. You are to analyze the process of changing automobile engine oil. The subject of the study is the service mechanic. The process begins when the mechanic directs the customer's arrival and ends when the customer pays for the services.

SOLUTION

Figure 2.17 shows the completed process chart. The process is broken into 21 steps. A summary of the times and distances traveled is shown in the upper right-hand corner of the process chart.

The times add up to 28 minutes, which does not allow much room for error if the 29-minute guarantee is to be met and the mechanic travels a total of 420 feet.

Process:	Changing engine oil
Subject:	Mechanic
Beginning:	Direct customer arrival
Ending:	Total charges, receive payment

Insert Step

Append Step

Remove Step

Summary

Activity		Number of Steps	Time (min)	Distance (ft)
Operation	●	7	16.50	
Transport	➡	8	5.50	420
Inspect	■	4	5.00	
Delay	◗	1	0.70	
Store	▼	1	0.30	

Step No.	Time (min)	Distance (ft)	●	➡	■	◗	▼	Step Description
1	0.80	50.0		X				Direct customer into service bay
2	1.80		X					Record name and desired service
3	2.30				X			Open hood, verify engine type, inspect hoses, check fluids
4	0.80	30.0		X				Walk to customer in waiting area
5	0.60		X					Recommend additional services
6	0.70					X		Wait for customer decision
7	0.90	70.0		X				Walk to storeroom
8	1.90		X					Look up filter number(s), find filter(s)
9	0.40				X			Check filter number(s)
10	0.60	50.0		X				Carry filter(s) to service pit
11	4.20		X					Perform under-car services
12	0.70	40.0		X				Climb from pit, walk to automobile
13	2.70		X					Fill engine with oil, start engine
14	1.30				X			Inspect for leaks
15	0.50	40.0		X				Walk to pit
16	1.00				X			Inspect for leaks
17	3.00		X					Clean and organize work area
18	0.70	80.0		X				Return to auto, drive from bay
19	0.30						X	Park the car
20	0.50	60.0		X				Walk to customer waiting area
21	2.30		X					Total charges, receive payment

FIGURE 2.17 Process Chart for Changing Engine Oil

Solved Problem 3

What improvement can you make in the process shown in Figure 2.17?

SOLUTION

Your analysis should verify the following three ideas for improvement. You may also be able to come up with others.

a. **Move Step 17 to Step 21.** Customers should not have to wait while the mechanic cleans the work area.

b. **Store Small Inventories of Frequently Used Filters in the Pit.** Steps 7 and 10 involve travel to and from the storeroom. If the filters are moved to the pit, a copy of the reference material must also be placed in the pit. The pit will have to be organized and well lighted.

c. **Use Two Mechanics.** Steps 10, 12, 15, and 17 involve running up and down the steps to the pit. Much of this travel could be eliminated. The service time could be shortened by having one mechanic in the pit working simultaneously with another working under the hood.

Solved Problem 4

Vera Johnson and Merris Williams manufacture vanishing cream. Their packaging process has four steps: (1) mix, (2) fill, (3) cap, and (4) label. They have had the reported process failures analyzed, which shows the following:

Process failure		Frequency
Lumps of unmixed product		7
Over- or underfilled jars		18
Jar lids did not seal		6
Labels rumpled or missing		29
	Total	60

Draw a Pareto chart to identify the vital failures.

SOLUTION

Defective labels account for 48.33 percent of the total number of failures:

$$\frac{29}{60} \times 100\% = 48.33\%$$

Improperly filled jars account for 30 percent of the total number of failures:

$$\frac{18}{60} \times 100\% = 30.00\%$$

The cumulative percent for the two most frequent failures is

$$48.33\% + 30.00\% = 78.33\%$$

Lumps represent $\frac{7}{60} \times 100\% = 11.67\%$ of failures; the cumulative percentage is

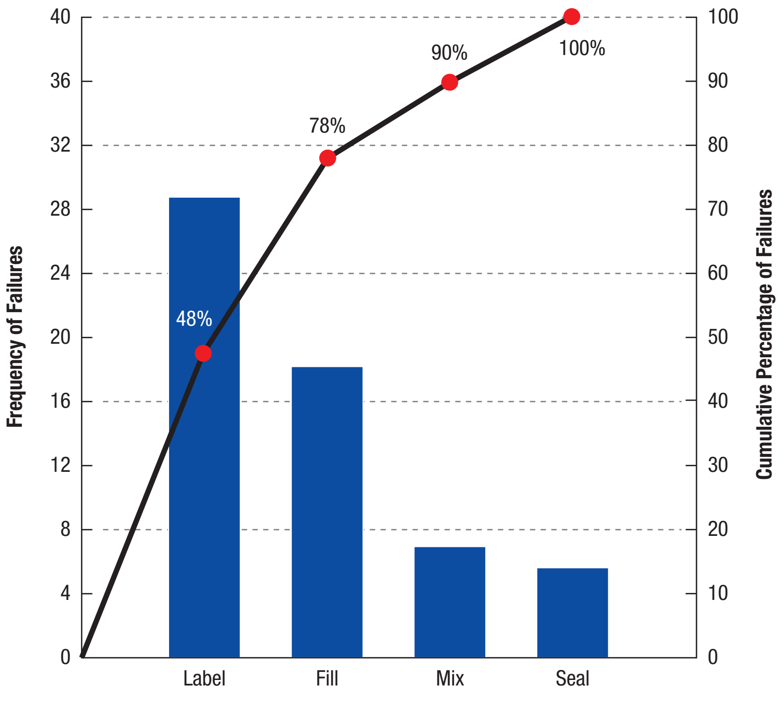
$$78.33\% + 11.67\% = 90.00\%$$

Defective seals represent $\frac{6}{60} \times 100\% = 10\%$ of failures; the cumulative percentage is

$$10\% + 90\% = 100.00\%$$

The Pareto chart is shown in Figure 2.18.

FIGURE 2.18 ▶
Pareto Chart



Discussion Questions

1. What processes at manufacturing firms are really service processes that involve considerable customer contact? Can customer contact be high, even if the process only has internal customers?
2. The customer-contact matrix, while important in any company, is considered especially crucial in businesses like the hospitality sector, where customer contact is a fundamental component. Hybrid office processes are often considered to constitute the best possible solution in such businesses since it involves high interaction with the customers, highly customized services, and flexible flows in the process. In which specific cases do you think hybrid solutions might not be optimal? Why or why not?
3. How do the process strategies of eBay and McDonald's differ, and how do their choices relate to customer-introduced variability?
4. Medical technology can outfit a patient with an artificial heart or cure vision defects with the touch of a laser. However, hospitals still struggle with their back-office processes, such as getting X-ray files from radiology on the fourth floor to the first-floor view boxes in the emergency room without having to send a runner. More than 90 percent of the estimated 30 billion health transactions each year are conducted by telephone, fax, or mail. To what extent, and how, can information technology improve productivity and quality for such processes? Remember that some doctors are not ready to give up their pads and pencils, and many hospitals have strong lines drawn around its departments, such as pharmacy, cardiology, radiology, and pediatrics.
5. Consider the range of processes in the financial services industry. What position on the customer-contact matrix would the process of selling financial services to municipalities occupy? The process of preparing monthly fund balance reports? Explain why they would differ.
6. Rate operators at a call center, who respond to queries from customers who call in about the company's product, on each of the five dimensions of customer contact in Table 2.1. Use a seven-point scale, where 1 = very low and 7 = very high. For example, the operators newer are physically present with the customer, and so they would get a score of 1 for physical presence. Explain your ratings, and then calculate a combined score for the overall customer contact. Did you use equal weights in calculating the combined score? Why or why not? Where is your process positioned on the customer-contact matrix? Is it properly aligned? Why or why not?
7. Continuous improvement recognizes that many small improvements add up to sizable benefits. Will continuous improvement take a company at the bottom of an industry to the top? Explain.
8. The Hydro-Electric Company (HEC) has three sources of power. A small amount of hydroelectric power is generated by damming wild and scenic rivers; a second source of power comes from burning coal, with emissions that create acid rain and contribute to global warming; the third source of power comes from nuclear fission. HEC's coal-fired plants use obsolete pollution-control technology, and an investment of several hundred million dollars would be required to update it. Environmentalists urge HEC to promote conservation and purchase power from suppliers that use the cleanest fuels and technology.

   However, HEC is already suffering from declining sales, which have resulted in billions of dollars invested in idle equipment. Its large customers are taking advantage of laws that permit them to buy power from low-cost suppliers. HEC must cover the fixed costs of idle capacity by raising rates charged to its remaining customers or face defaulting on bonds (bankruptcy). The increased rates motivate even more customers to seek low-cost suppliers, the start of a death spiral for HEC. To prevent additional rate increases, HEC implements a cost-cutting program and puts its plans to update pollution controls on hold.

   Form sides and discuss the ethical, environmental, and political issues and trade-offs associated with HEC's strategy.
9. Benchmarking, a valuable and quite efficient tool for process redesigning, often encounters serious challenges during its implementation. One of the most pronounced difficulties is in collecting benchmarking data. This is why sometimes internal benchmarking—selecting the use of an organizational unit with superior performance as a benchmark—is the only option available. There are many examples that can be cited in this context, more than often carried out in big organizations due to the cost involved, which have in common a series of factors that have to be analyzed. Answer the following questions based on what has been discussed in the chapter:
   a. What constitutes the best practices of benchmarking?
   b. When is the benchmarking most effective?
   c. Why is benchmarking such an attractive method of performance improvement, to the point that is often preferred to others?
   d. Does the benchmarking affect strategic or operational processes?
   e. Many typologies of benchmarking have been developed in doctrine to describe the nature and scope of benchmarking activities. One particularly useful adopt this categories for evaluation:
      - Internal
      - Competitive
      - Functional
      - Generic

Problems

The OM Explorer and POM for Windows software is available to all students using the 11th edition of this textbook. Go to **http://www.pearsonglobaleditions.com/Krajewski** to download these computer packages. If you purchased MyOMLab, you also have access to Active Models software and significant help in doing the following problems. Check with your instructor on how best to use these resources. In many cases, the instructor wants you to understand how to do the calculations by hand. At the least, the software provides a check on your calculations. When calculations are particularly complex and the goal is interpreting the results in making decisions, the software replaces entirely the manual calculations.

Process Strategy Decisions

Problems 1, 2, and 3 apply break-even analysis (discussed in Supplement A, "Decision Making Models") to process decisions.

1. Dr. Gulakowicz is an orthodontist. She estimates that adding two new chairs will increase fixed costs by $155,000, including the annual equivalent cost of the capital investment and the salary of one more technician. Each new patient is expected to bring in $2,920 per year in additional revenue, with variable costs estimated at $1,010 per patient. The two new chairs will allow Dr. Gulakowicz to expand her practice by as many as 200 patients annually. How many patients would have to be added for the new process to break even?

2. Two different manufacturing processes are being considered for making a new product. The first process is less capital-intensive, with fixed costs of only $50,000 per year and variable costs of $700 per unit. The second process has fixed costs of $400,000 but has variable costs of only $200 per unit.

   a. What is the break-even quantity beyond which the second process becomes more attractive than the first?

   b. If the expected annual sales for the product is 800 units, which process would you choose?

3. Two different manufacturing processes are being considered for making a new product. The first process is less capital-intensive, with fixed costs of only $46,400 per year and variable costs of $720 per unit. The second process has fixed costs of $400,100 but has variable costs of only $210 per unit.

   a. What is the break-even quantity, beyond which the second process becomes more attractive than the first?

   b. If the expected annual sale for the product is 840 units, which process would you choose?

Documenting and Evaluating the Process

4. Consider the Custom Molds, Inc., case at the end of this chapter. Prepare a flowchart of the mold fabrication process and the parts manufacturing process, showing how they are linked. For a good tutorial on how to create flowcharts, see **http://www.hci.com.au/hcisite5/library/materials/Flowcharting.htm**. Also check out the Flowcharting Tutor in Excel in MyOMLab.

5. Do Problem 4 using a process chart spreadsheet of your own design, one that differs from the *Process Chart* Solver in OM Explorer. It should have one or more columns to record information or metrics that you think are relevant, be they external customer contacts, time delays, completion times, percent rework, costs, capacity, or demand rates. Your entries should show what information you would collect, even though only part of it is available in the case.

6. Founded in 1970, ABC is one of the world's largest insurance companies with locations in 28 countries. Given the following description, flowchart the new policy setup process as it existed in 1970:

   Individual customers who wanted to set up a new policy would visit one of ABC's 70 branch offices or make contact with an agent. They would then fill out an application and sometimes attach a check. The branch office then sent the application package through company mail to the XYZ division in London. In addition, a customer might also fill out the application at home and send it directly to any number of ABC locations, which would then transfer it to the London operation. Once received, XYZ separated the various parts of the application, then scanned and digitized it. The electronic image was then retrieved from a server and delivered to an associate's desktop client computer. The associate was responsible for entering the information on the form into the appropriate database. If the information supplied on the application was complete, a confirmation notice was automatically printed and sent to the customer. If the information was incomplete, then another associate, trained to deal with customers on the telephone, would call the customer to obtain the additional information. If the customer noticed something wrong on the confirmation notice received, she or he would either call a toll-free number or send in a letter describing the problem. The Customer Problem Resolution division dealt with problems arising at this point. An updated confirmation notice was sent to the customer. If the information was correct, the application transaction was complete.

7. Do Problem 6 using a process chart spreadsheet of your own design, one that differs from the *Process Chart* Solver in OM Explorer. It should have one or more columns to record information or metrics that you think should be collected to analyze the process (see Problem 5).

8. Prepare a flowchart of the field service division process at DEF, as described here. Start from the point where a call is received and end when a technician finishes the job.

DEF was a multibillion dollar company that manufactured and distributed a wide variety of electronic, photographic, and reprographic equipment used in many engineering and medical system applications. The Field Service Division employed 475 field service technicians, who performed maintenance and warranty repairs on the equipment sold by DEF. Customers would call DEF's National Service Center (NSC), which received about 3,000 calls per day. The NSC staffed its call center with about 40 call-takers. A typical incoming service call was received at the NSC and routed to one of the call-takers, who entered information about the machine, the caller's name, and the type of problem into DEF's mainframe computer. In some cases, the call-taker attempted to help the customer fix the problem. However, call-takers were currently only able to avoid about 10 percent of the incoming emergency maintenance service calls. If the service call could not be avoided, the call-taker usually stated the following script: "Depending upon the availability of our technicians, you should expect to see a technician sometime between now and (now +X)." ("X" was the target response time based on the model number and the zone.) This information was given to the customer because many customers wanted to know when a tech would arrive on site.

Call-takers entered service call information on DEF's computer system, which then sent the information electronically to the regional dispatch center assigned to that customer location. (DEF had four regional dispatch centers with a total of about 20 dispatchers.) Service call information was printed on a small card at the dispatch center. About every hour, cards were ripped off the printer and given to the dispatcher assigned to that customer location. The dispatcher placed each card on a magnetic board under the name of a tech that the dispatcher believed would be the most likely candidate for the service call, given the location of the machine, the current location of the tech, and the tech's training profile. After completing a service call, techs called the dispatcher in the regional dispatch center, cleared the call, and received a new call assigned by the dispatcher. After getting the service call from a dispatcher, a tech called the customer to give an expected time of arrival, drove to the customer site, diagnosed the problem, repaired the machine if parts were available in the van, and then telephoned the dispatcher for the next call. If the tech did not have the right parts for a repair, the tech informed the NSC, and the part was express mailed to the customer; the repair was done the next morning.

9. Big Bob's Burger Barn would like to graphically depict the interaction among its lunch-ordering customers and its three employees. Customers come into the restaurant and eat there rather than drive through and eat in the car. Using the brief process descriptions below, develop a service blueprint.

Fry Employee: receive customer order from counter employee, retrieve uncooked food, drop food into fry vat, wrap cooked food into special packaging, place wrapped items on service counter.

Grill Employee: receive customer order from counter employee, retrieve uncooked food, place food onto grill, build sandwich with requested condiments, deliver sandwich to Counter Employee.

Counter Employee: take order from customer, transmit appropriate orders to Fry and Grill Employee, transact payment, retrieve drinks, wrap sandwich, package order, and deliver order to customer.

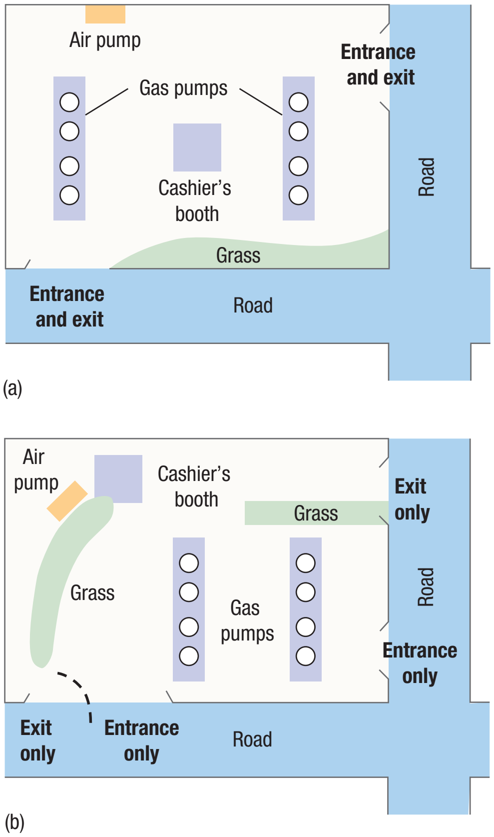
10. Your class has volunteered to work for Referendum 13 on the November ballot, which calls for free tuition and books for all college courses except Operations Management. Support for the referendum includes assembling 10,000 yard signs (preprinted water-resistant paper signs to be glued and stapled to a wooden stake) on a fall Saturday. Construct a flowchart and a process chart for yard sign assembly. What inputs in terms of materials, human effort, and equipment are involved? Estimate the amount of volunteers, staples, glue, equipment, lawn and garage space, and pizza required.

11. Suppose you are in charge of a large mailing to the alumni of your college inviting them to contribute to a scholarship fund. The letters and envelopes have been individually addressed (mailing labels were not used). The letters are to be processed (matched with correct envelope, time estimated to be 0.2 minutes each), folded (0.12 minutes each), and stuffed into the correct envelope (0.10 minutes each). The envelopes are to be sealed (0.05 minutes each), and a large commemorative stamp is to be placed in the upper right-hand corner of each envelope (0.10 minutes each).

- **a.** Make a process chart for this activity, assuming that it is a one-person operation.
- **b.** Estimate how long it will take to stuff, seal, and stamp 2,000 envelopes. Assume that the person doing this work is paid \$8 per hour. How much will it cost to process 2,000 letters?
- **c.** Consider each of the following process changes. Which changes would reduce the time and cost of the current process?
  - Each letter has the same greeting, "Dear Alumnus or Alumna," instead of the person's name.
  - Mailing labels are used and have to be put on the envelopes (0.10 minutes each).
  - Prestamped envelopes are used.
  - Envelopes are stamped by a postage meter which can stamp 200 letters per minute.
  - Window envelopes are used.
  - A preaddressed envelope is included with each letter for contributions (adds 0.05 minutes to stuffing step).
- **d.** Would any of these changes be likely to reduce the effectiveness of the mailing? If so, which ones? Why?
- **e.** Would the changes that increase time and cost be likely to increase the effectiveness of the mailing? Why or why not?

12. Diagrams of two self-service gasoline stations, both located on corners, are shown in Figure 2.19(a) and (b). Both have two rows of four pumps and a booth at which an attendant receives payment for the gasoline. At neither station is it necessary for the customer to pay in advance. The exits and entrances are marked on the diagrams. Analyze the flows of cars and people through each station.

- **a.** Which station has the more efficient flows from the standpoint of the customer?
- **b.** Which station is likely to lose more potential customers who cannot gain access to the pumps because another car is headed in the other direction?
- **c.** At which station can a customer pay without getting out of the car?



▲ **FIGURE 2.19**
Two Self-Service Gasoline Stations

13. The management of the Just Like Home Restaurant has asked you to analyze some of its processes. One of these processes is making a single-scoop ice cream cone. Cones can be ordered by a server (for table service) or by a customer (for takeout).

Figure 2.20 illustrates the process chart for this operation.

- The ice cream counter server earns $10 per hour (including variable fringe benefits).
- The process is performed 10 times per hour (on average).
- The restaurant is open 363 days a year, 10 hours a day.

a. Complete the Summary (top-right) portion of the chart.

b. What is the total labor cost associated with the process?

c. How can this operation be made more efficient? Make a process chart using OM Explorer's *Process Charts* Solver of the improved process. What are the annual labor savings if this new process is implemented?

14. As a graduate assistant, your duties include grading and keeping records for Operations Management course homework assignments. Five sections for 40 students each are offered each semester. A few graduate students attend sections 3 and 4. Graduate students must complete some extra work to higher standards for each assignment. Every student delivers (or is supposed to deliver) directly to (under) the door of your office one homework assignment every Tuesday. Your job is to correct the homework, record grades, sort the papers by class section, sort by student last name in

FIGURE 2.20 ▶
Process Chart for Making Ice Cream Cones

Process:	Making one ice cream cone
Subject:	Server at counter
Beginning:	Walk to cone storage area
Ending:	Give it to server or customer

Insert Step

Append Step

Remove Step

Summary

Activity		Number of Steps	Time (min)	Distance (ft)
Operation	●			
Transport	➡			
Inspect	■			
Delay	◗			
Store	▼			

Step No.	Time (min)	Distance (ft)	●	➡	■	◗	▼	Step Description
1	0.20	5.0		X				Walk to cone storage area
2	0.05		X					Remove empty cone
3	0.10	5.0		X				Walk to counter
4	0.05		X					Place cone in holder
5	0.20	8.0		X				Walk to sink area
6	0.50					X		Ask dishwasher to wash scoop
7	0.15	8.0		X				Walk to counter with clean scoop
8	0.05		X					Pick up empty cone
9	0.10	2.5		X				Walk to flavor ordered
10	0.75		X					Scoop ice cream from container
11	0.75		X					Place ice cream in cone
12	0.25				X			Check for stability
13	0.05	2.5		X				Walk to order placement area
14	0.05		X					Give server or customer the cone

alphabetical order, and return the homework papers to the appropriate instructors (not necessarily in that order). There are some complications. A fair majority of the students sign their names legibly, others identify work with their correct ID number, and a few do neither. Rarely do students identify their section number or graduate status. Prepare a list of process chart steps and place them in an efficient sequence.

15. At the Department of Motor Vehicles (DMV), the process of getting license plates for your car begins when you enter the facility and take a number. You walk 50 feet to the waiting area. During your wait, you count about 30 customers waiting for service. You notice that many customers become discouraged and leave. When a number is called, if a customer stands, the ticket is checked by a uniformed person, and the customer is directed to the available clerk. If no one stands, several minutes are lost while the same number is called repeatedly. Eventually, the next number is called, and more often than not, that customer has left too. The DMV clerk has now been idle for several minutes but does not seem to mind.

After 4 hours, your number is called and checked by the uniformed person. You walk 60 feet to the clerk, and the process of paying city sales taxes is completed in four minutes. The clerk then directs you to the waiting area for paying state personal property tax, 80 feet away. You take a different number and sit down with some different customers who are just renewing licenses. There is a 1-hour, 40-minute wait this time, and after a walk of 25 feet you pay property taxes in a process that takes two minutes. Now that you have paid taxes, you are eligible to pay registration and license fees. That department is 50 feet away, beyond the employees' cafeteria.

The registration and license customers are called in the same order in which personal property taxes were paid. There is only a 10-minute wait and a 3-minute process. You receive your license plates, take a minute to abuse the license clerk, and leave exactly 6 hours after arriving.

Make a process chart using OM Explorer's *Process Charts* Solver to depict this process, and suggest improvements.

16. Refer to the process chart for the automobile oil change in Solved Problem 2. Calculate the annual labor cost if:

- The mechanic earns $40 per hour (including variable fringe benefits).
- The process is performed twice per hour (on average).
- The shop is open 300 days a year, 10 hours a day.

a. What is the total labor cost associated with the process?

b. If steps 7, 10, 12, and 15 were eliminated, estimate the annual labor savings associated with implementing this new process.

17. A time study of an employee assembling peanut valves resulted in the following set of observations. What is the standard time, given a performance rating of 95 percent and an allowance of 14 percent of the total normal time?

Average Time (seconds)	Observations
14	19
23	17
29	16

18. An initial time study was done on a process with the following results (in minutes). Based on the data obtained so far, assuming an allowance of 20 percent of the normal time, what do you estimate for the time per customer served, based on this preliminary sample?

Element	Performance Rating	Obs 1	Obs 2	Obs 3	Obs 4	Obs 5
Element 1	70	4	3	5	4	3
Element 2	110	8	10	9	11	10
Element 3	90	6	8	7	7	6

19. A work sampling study was conducted to determine the proportion of the time a worker is idle. The following information was gathered on a random basis:

Day	Number of Times Worker Idle	Total Number of Observations
Monday	17	44
Tuesday	18	56
Wednesday	14	48
Thursday	16	60

a. Based on these preliminary results, what percent of the time is the worker working?

b. If idle time is judged to be excessive, what additional categories might you add to a follow-up work sampling study to identify the root causes?

20. A contractor is preparing a bid to install swimming pools at a new housing addition. The estimated time to build the first pool is 27 hours. The contractor estimates a 50 percent learning rate. Without using the computer:

a. How long do you estimate the time required to install the second pool?

b. How long do you estimate the time required to install the fourth pool?

21. Return to Problem 20. Using OM Explorer's Learning Curves Solver, how long do you estimate the time required to install the fifth pool? What is your estimate of the total time for all five pools?

22. On RainTite Window's manual assembly line, a new employee can usually assemble their first window unit in 30 minutes. Management assumes a 90 percent learning rate.

a. How long should a new employee take to assemble their second window if management is correct in their assumption? How long should the 16th window take?

b. On RainTite's semi-automated line, a new employee takes 45 minutes to assemble their first window; however, the learning rate is 75 percent. At how many windows produced will the semi-automated line's employee take less time to produce a window than an employee on the manual line?

23. The manager of Perrotti's Pizza collects data concerning customer complaints about pizza delivery. Either the pizza arrives late, or the wrong pizza is delivered.

Problem	Frequency
Topping is stuck to box lid	17
Pizza arrives late	35
Wrong topping or combination	9
Wrong style of crust	6
Wrong size	4
Pizza is partially eaten	3
Pizza never arrives	6

a. Use a Pareto chart to identify the "vital few" delivery problems. Comment on potential root causes of these problems and identify any especially egregious quality failures.

b. The manager of Perrotti's Pizza is attempting to understand the root causes of late pizza delivery and has asked each driver to keep a log of specific difficulties that create late deliveries. After one week, the logs included the following entries:

delivery vehicle broke down, couldn't make it across town to deliver second pizza in time, couldn't deliver four pizzas to four different customers in time, kitchen was late in producing order, got lost, order ticket was lost in production, couldn't read address on ticket and went to wrong house.

Organize these causes into a cause-and-effect diagram.

24. Smith, Schroeder, and Torn (SST) is a short-haul household furniture moving company. SST's labor force, selected from the local community college football team, is temporary and part-time. SST is concerned with recent complaints, as tabulated on the following tally sheet:

Complaint	Tally
Broken glass	卌 卌 III
Delivered to wrong address	卌 IIII
Furniture rubbed together while on truck	卌 卌 卌 卌
Late delivery	卌
Late arrival for pickup	卌 卌 卌 III
Missing items	卌 卌 卌 卌 卌 I
Nicks and scratches from rough handling	卌 卌
Soiled upholstery	卌 III

a. Draw a bar chart and a Pareto chart using OM Explorer to identify the most serious moving problems.

b. The manager of Smith, Schroeder, and Torn is attempting to understand the root causes of complaints. He has compiled the following list of issues that occurred during problem deliveries:

truck broke down, ran out of packing boxes, multiple deliveries in one day caused truck to be late, no furniture pads, employee dropped several items, drive got lost on route to address, ramp into truck was bent, no packing tape, new employee doesn't know how to pack, moving dolly has broken wheel, employee late to work

Organize these causes into a cause-and-effect diagram.

25. Rick DeNeefe, manager of the Golden Valley Bank credit authorization department, recently noticed that a major competitor was advertising that applications for equity loans could be approved within two working days. Because fast credit approval was a competitive priority, DeNeefe wanted to see how well his department was doing relative to the competitor's. Golden Valley stamps each application with the date and time it is received and again when a decision is made. A total of 99 applications were received in March. The time required for each decision, rounded to the nearest hour, is shown in the following table. Golden Valley's employees work 8 hours per day.

Decision Process Time (hours)	Frequency
8	5
11	15
14	29
17	11
20	26
23	3
24	10
Total	99

a. Draw a bar chart for these data.

b. Analyze the data. How is Golden Valley Bank doing with regard to this competitive priority?

26. Last year, the manager of the service department at East Woods Ford instituted a customer opinion program to find out how to improve service. One week after service on a vehicle was performed, an assistant would call the customer to find out whether the work had been done satisfactorily and how service could be improved. After one year of gathering data, the assistant discovered that the complaints could be grouped into the following five categories:

Complaint	Frequency
Unfriendly atmosphere	5
Long wait for service	17
Price too high	20
Incorrect bill	8
Needed to return to correct problem	50
Total	100

a. Use OM Explorer to draw a bar chart and a Pareto chart to identify the significant service problems.

b. Categorize the following causes of complaints into a cause-and-effect diagram: tools, scheduling, defective parts, training, billing system, performance measures, diagnostic equipment, and communications.

27. Oregon Fiber Board makes roof liners for the automotive industry. The manufacturing manager is concerned about product quality. She suspects that one particular failure, tears in the fabric, is related to production-run size. An assistant gathers the following data from production records:

Run	Size	Failures (%)	Run	Size	Failures (%)
1	1,000	3.5	11	6,500	1.5
2	4,100	3.8	12	1,000	5.5
3	2,000	5.5	13	7,000	1.0
4	6,000	1.9	14	3,000	4.5
5	6,800	2.0	15	2,200	4.2
6	3,000	3.2	16	1,800	6.0
7	2,000	3.8	17	5,400	2.0
8	1,200	4.2	18	5,800	2.0
9	5,000	3.8	19	1,000	6.2
10	3,800	3.0	20	1,500	7.0

a. Draw a scatter diagram for these data.

b. Does there appear to be a relationship between run size and percent failures? What implications does this data have for Oregon Fiber Board's business?

28. Grindwell, Inc., a manufacturer of grinding tools, is concerned about the durability of its products, which depends on the permeability of the sinter mixtures used in production. Suspecting that the carbon content might be the source of the problem, the plant manager collected the following data:

Carbon Content (%)	Permeability Index
5.5	16
3.0	31
4.5	21
4.8	19
4.2	16
4.7	23
5.1	20
4.4	11
3.6	20

a. Draw a scatter diagram for these data.

b. Is there a relationship between permeability and carbon content?

c. If low permeability is desirable, what does the scatter diagram suggest with regard to the carbon content?

29. The operations manager for Superfast Airlines at Chicago's O'Hare Airport noticed an increase in the number of delayed flight departures. She brainstormed possible causes with her staff:

- Aircraft late to gate
- Acceptance of late passengers
- Passengers arriving late at gate
- Passenger processing delays at gate
- Late baggage to aircraft
- Other late personnel or unavailable items
- Mechanical failures

Draw a cause-and-effect diagram to organize the possible causes of delayed flight departures into the following major categories: equipment, personnel, material, procedures, and other factors beyond managerial control. Provide a detailed set of causes for each major cause identified by the operations manager, and incorporate them in your cause-and-effect diagram.

30. Plastomer, Inc., specializes in the manufacture of high-grade plastic film used to wrap food products. Film is rejected and scrapped for a variety of reasons (e.g., opacity, high carbon content, incorrect thickness or gauge, scratches, etc.). During the past month, management collected data on the types of rejects and the amount of scrap generated by each type. The following table presents the results:

Type of Failure	Amount of Scrap (lbs.)
Air bubbles	500
Bubble breaks	19,650
Carbon content	150
Unevenness	3,810
Thickness or gauge	27,600
Opacity	450
Scratches	3,840
Trim	500
Wrinkles	10,650

Draw a Pareto chart to identify which type of failure management should attempt to eliminate first.

31. Management of a shampoo bottling company introduced a new 13.5-ounce pack and used an existing machine, with some modifications, to fill it. To measure filling consistency by the modified machine (set to fill 13.85 ounces), an analyst collected the following data (volume in ounces) for a random sample of 100 bottles:

a. Draw a histogram for these data.

b. Bottles with less than 12.85 ounces or more than 14.85 ounces are considered to be out of specification. Based on the sample data, what percentage of the bottles filled by the machine will be out of specification?

Bottle Volume (ounces)									
13.0	13.3	13.6	13.2	14.0	12.9	14.2	12.9	14.5	13.5
14.1	14.0	13.7	13.4	14.4	14.3	14.8	13.9	13.5	14.3
14.2	14.1	14.0	13.9	13.9	14.0	14.5	13.6	13.3	12.9
12.8	13.1	13.6	14.5	14.6	12.9	13.1	14.4	14.0	14.4
13.1	14.1	14.2	12.9	13.3	14.0	14.1	13.1	13.6	13.7
14.0	13.6	13.2	13.4	13.9	14.5	14.0	14.4	13.9	14.6
12.9	14.3	14.0	12.9	14.2	14.8	14.5	13.1	12.7	13.9
13.6	14.4	13.1	14.5	13.5	13.3	14.0	13.6	13.5	14.3
13.2	13.8	13.7	12.8	13.4	13.8	13.3	13.7	14.1	13.7
13.7	13.8	13.4	13.7	14.1	12.8	13.7	13.8	14.1	14.3

32. This problem should be solved as a team exercise:

Shaving is a process that most men perform each morning. Assume that the process begins at the bathroom sink with the shaver walking (say, 5 feet) to the cabinet (where his shaving supplies are stored) to pick up bowl, soap, brush, and razor. He walks back to the sink, runs the water until it gets warm, lathers his face, shaves, and inspects the results. Then he rinses the razor; dries his face; walks over to the cabinet to return the bowl, soap, brush, and razor; and comes back to the sink to clean it up and complete the process.

a. Develop a process chart for shaving. (Assume suitable values for the time required for the various activities involved in the process.)

b. Brainstorm to generate ideas for improving the shaving process. Having fewer than 20 ideas is unacceptable. (Do not try to evaluate the ideas until the group has compiled as complete a list as possible. Otherwise, judgment will block creativity.)

33. At Conner Company, a custom manufacturer of printed circuit boards, the finished boards are subjected to a final inspection prior to shipment to its customers. As Conner's quality assurance manager, you are responsible for making a presentation to management on quality problems at the beginning of each month. Your assistant has analyzed the reject memos for all the circuit boards that were rejected during the past month. He has given you a summary statement listing the reference number of the circuit board and the reason for rejection from one of the following categories:

A = Poor electrolyte coverage
B = Improper lamination
C = Low copper plating
D = Plating separation
E = Improper etching

For 50 circuit boards that had been rejected last month, the summary statement showed the following:

C B C C D E C C B A D A C C C B C A C D C A C C B
A C A C B C C A C A A C C D A C C C E C C A B A C

a. Prepare a tally sheet (or checklist) of the different reasons for rejection.

b. Develop a Pareto chart to identify the more significant types of rejection.

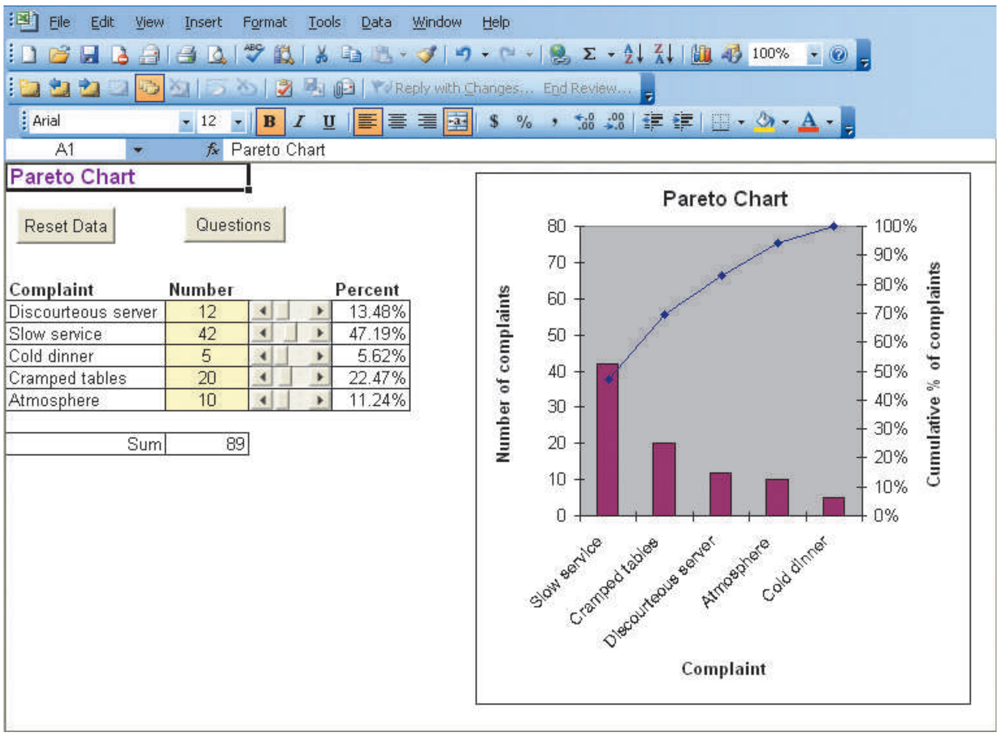
c. Examine the causes of the most significant type of defect, using a cause-and-effect diagram.

Active Model Exercise

This Active Model appears in MyOMLab. Continuing on with Example 2.2, it allows you to evaluate the structure of a Pareto chart.

QUESTIONS

1. What percentage of overall complaints does discourteous service account for?
2. What percentage of overall complaints do the three most common complaints account for?
3. How does it affect the chart if we eliminate discourteous service?



VIDEO CASE Process Analysis at Starwood

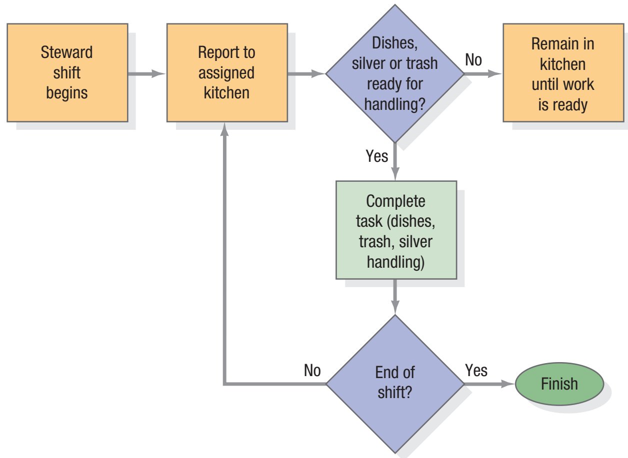
The features and layout of The Phoenician property of Starwood Hotels and Resorts at Scottsdale, Arizona, are shown in the following figure. Starwood Hotels and Resorts is no stranger to process improvement. In fact, the president's letter in a recent annual report stated that through "…benchmarking, Six Sigma, and recognition of excellence, [Starwood is] driving results in a virtual cycle of self-improvement at all levels of the Company." Recognizing that improved processes in one department of a single hotel, if rolled out across the organization, could lead to significant improvements, the company recently created a program called Power of Innovation, or POI.

The Power of Innovation program in Starwood seeks to capture best practices that exist throughout hotels across all brands in North America. An internal team with expertise in kitchen preparation and production, laundry, stewarding, front office, and housekeeping works with individual properties to build upon and maximize the existing knowledge of local property management teams. The team usually spends about a week on property entrenched in operations to really see day-to-day activity over an extended period. Of particular interest is scheduling the workforce to meet the demand of each hotel's individual operations while streamlining operations processes.

At the Westin Galleria-Oaks in Houston, Texas, for example, the POI team helped management achieve a 6 percent productivity improvement in the kitchen preparation and production job, with a reduction of 2,404 hours used and $23,320 in annual payroll savings alone. At the same time, other POI projects at the hotel generated an additional $14,400 in annual payroll savings.

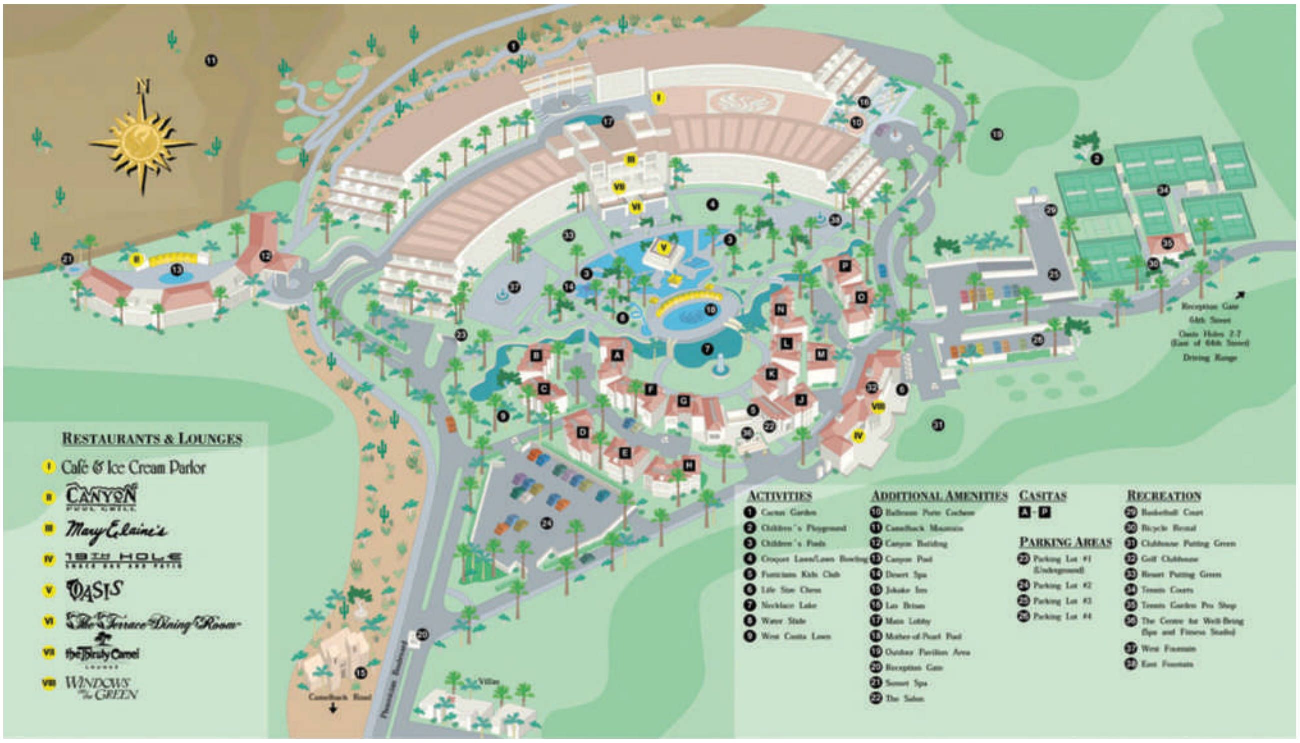
The Phoenician in Scottsdale also had a visit from the POI team. One area the team focused on was stewarding. The typical stewarding process includes the following duties: dishwashing, kitchen trash removal, polishing silver, and assisting with banquet meal food prep lines. Stewards support eight kitchens and two bakeries and work with housekeeping in keeping public areas, such as restrooms and pool cabanas, clean.

A flowchart that diagrams the existing stewarding process that the team documented is shown in the figure. In any given day, a particular steward may provide support to more than one kitchen and be called upon to do a variety of tasks.



Before the POI team arrived, stewards were dedicated to a particular kitchen or area during their shift. Each kitchen required stewarding coverage as outlined by the executive chef, so more than one steward may be assigned to an area. A certain amount of stewarding work could be forecast by the food and beverage manager, based on scheduled banquets, afternoon teas, conference buffets, and restaurant reservations. Considerable uncertainty also arose from traffic generated by leisure travelers and local clientele, meaning that stewards assigned to designated areas periodically did not have a steady flow of work.

On a weekly basis, activity levels for the dedicated stewarding staff were determined, based on executive chef input. Other factors considered in the weekly planning included prior year activity, special events and holidays, and



number of children. With this information, the executive steward created a summary of all meals, called covers, by location, date, and time of day. Then an Excel spreadsheet template was used to create the schedule for deployment of stewarding staff throughout the resort's kitchens and restaurants.

In performing its analysis, the POI team examined staff availability, banquet events, restaurants, occupied room counts, and other drivers of business to areas supported by stewards. Time studies were done to determine how far stewards were traveling throughout the property, and how long it took to perform each stewarding task. Some restaurants and kitchens did not require full-time coverage by a steward, so the steward would be assigned multiple kitchens to fill a work shift. In the case of coverage between the 19th Hole restaurant on one side of the resort and the Canyon Building on the other side, that steward would walk one-half mile, one way, to take care of duties in both locations because they lacked enough work for a dedicated steward in each location.

Often, stewards had downtime as they waited for banquet dishes to be cleared, or kitchen pots and utensils to be brought in for cleaning. Some restaurants had china with special cleaning requirements, meaning those dishes had to be handwashed instead of being placed in an automated sanitizing dishwasher. This situation required a dedicated steward to perform that task.

Time studies revealed how long it took stewards to move from one kitchen to the next. The studies also helped the POI team understand how long it took to wash dishes in the five-star restaurant versus the casual poolside dining area's kitchen. Additionally, the studies uncovered building design and landscaping limitations that prevented staff from moving between kitchens quickly. In some cases, a maze of corridors added miles to the distances covered each day, and thick privacy hedges barred entry to sidewalk shortcuts.

QUESTIONS

1. How can the management specifically improve the stewarding process at The Phoenician? Using the information provided, create a flowchart illustrating the new process.
2. What are the benefits that the POI program can bring to Starwood? Can these benefits be extended to other processes and properties within the Starwood system?
3. Of the seven mistakes organizations can make when managing processes (see last section of this chapter), which ones might Starwood be most at risk of making? Why?

CASE Sims Metal Management

Background

Sims Metal Management is the world's largest metal recycler and has operations over the five continents with more than 90 years of experience in the business, which started in Australia. Every year they process over 2 million metric tons of ferrous and nonferrous materials in the United Kingdom across 36 metal recycling locations. The company recovers end-of-life and abandoned cars, old machinery, nonhazardous consumer goods, even trains. There are growing concerns in the manufacturing world over the global supply chain of commodities. Some materials such as rare earth elements are becoming increasingly expensive due to a restraint of their export from China and an ever-increasing demand from the electronic industry. Furthermore, the sustained demand from BRIC countries (Brazil, Russia, India, and China, all developing economies, but with tremendous potential thanks to their territories and increasing presence in world-trade) has raised commodity prices on iron ore, steel, and oil, while only naming the most common. Experts agree that the world has entered an upward trend in commodity prices at the beginning of the century and it is identified as a supercycle projected to last 30 years.

Recycling as a Sustainable Business Practice

Governments and large industries are starting to look into recycling end-of-life products, ranging from cars to cell phones to retrieve these materials and their strategic supply chains are evolving accordingly. Sims Metal Management and other recyclers are, no doubt, on a growing market trend. In addition to the economic laws of supply and demand, the European Union—in its bid to become the most environmentally friendly economic group—has issued directives and laws to channel the disposal of hazardous materials from landfills and make compulsory the use of specialized companies to dismantle old factories.

Sims Metal Management has become the largest world recycler thanks to a series of acquisitions over the past years and notably in the United Kingdom in 2002. The competition is fierce and Sims proposes competitive prices on nonferrous metals (aluminum, brass, and copper) thanks to high recovery rates. These can be achieved owing to an efficient supply chain and well-designed internal processes.

SIMS Metal Strategy

The company's strategy, to stay the number one metals recycler in the UK, relies on one fundamental principle: low operating costs with high recycling rates to offer the best quotes when bidding to recycle metals, when decommissioning a plant for example. This strategy is achieved thanks to economies of scales, as for any manufacturing business, and thanks to their recycling processes. To keep its operating costs to minimum, the company has sought, and received, the ISO 9000:2001 certification. The certification focuses on Quality Management, with the aim to satisfy customers but also to continually improve processes to sustain productivity gains, hence their competitive advantage. The operations of SIMS Metal ensure cars are shredded in a minimum amount of time. The company also minimizes the amount of manual labor to keep its operating costs down. However, final steps of the shredding process need manual labor to finalize materials separation. The recycling industry is increasingly looking into manufacturing techniques to improve their operations. The car manufacturing industry has many methods that can be adapted to the recycling business: Lean, Six Sigma, Control Charts, etc. All these techniques have the common aim to reduce overall lead times and sustain productivity gains, thus serving the company strategy to remain price competitive.

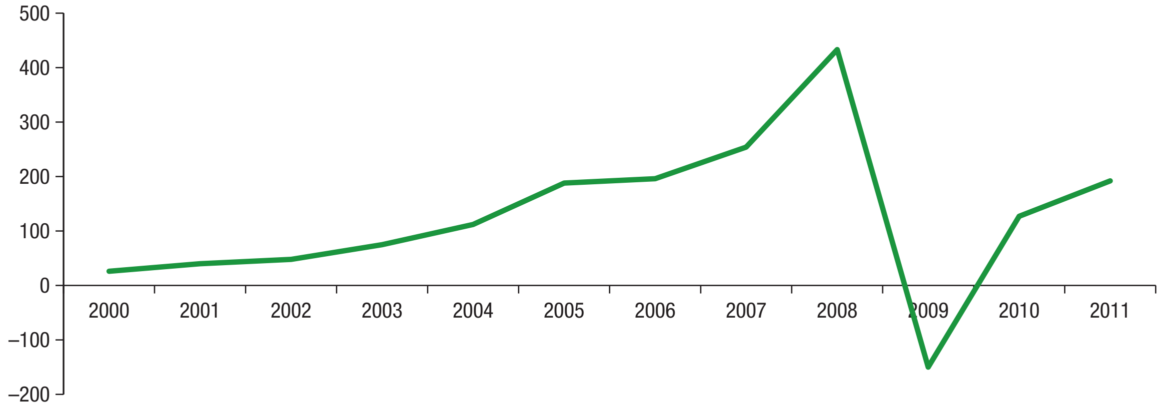
Metal Shredding Process

One of their most impressive processes is the treatment of end-of-life of vehicles (ELV). The cars are collected thanks to their transportation network linking the company 36 metals and shredding recycling locations across England and Wales to a network of 35 scrap metal dealers. The main difference between SIMS and other recyclers in the UK is their integrated operations.

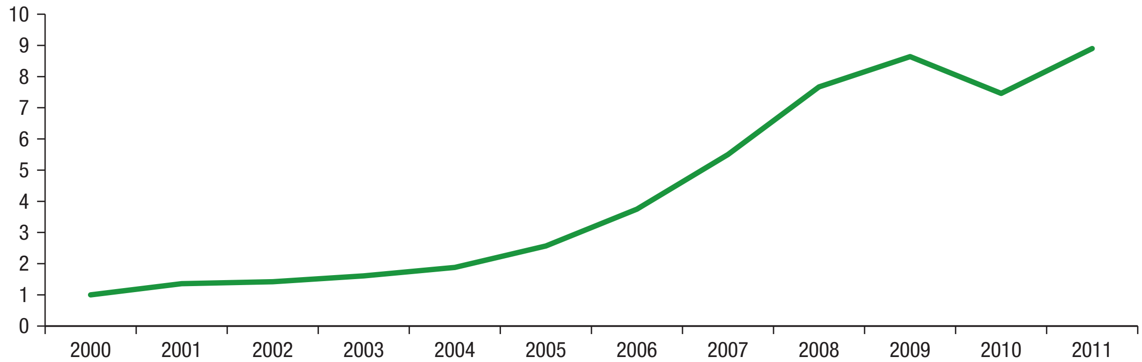
With their network of scrap dealers and delivery trucks, they ensure the constant flow of materials to the recycling facilities. Once metal is collected, it has to be transformed into a value-added product as fast as possible, otherwise it is only waste, without any value. For recyclers value is created with metals separation and cleaning.

To ensure the highest environmental standards, the cars are first depolluted. They are entered in the database and the owner is issued a certificate of destruction. Wheels, battery, bumpers, seats, and exhaust pipe are removed. Some of these elements, if still of good quality, will then be resold as secondhand goods. The car is then elevated and a technician safely drains fuel, waste oil, brake fluid, and coolant from the different tanks. Having been stripped of its major pollutants, the shredding process can start.

The car is loaded on a large conveyor and goes through two flattening wheels. The reduced metal is shredded in hundreds of parts containing ferrous, and nonferrous materials, but also plastic. The shredded elements pass through a chamber equipped with a powerful wind turbine to remove light materials (foam and cloth, for example). The remaining heavy materials pass in front of powerful magnets to separate ferrous and nonferrous components. Operatives now remove any nonferrous product that might not have been separated in the previous stage.



▲ **FIGURE 2.21**
SIMS Metal Management Global profits after tax in million US$



▲ **FIGURE 2.22**
SIMS Metal Management Global revenue in billion US$

Electronic Waste Recycling Process

In addition to recycling metal, Sims is recycling more and more electronic and electrical waste.

European Union is restricting the disposal of electronic waste in landfills as batteries contain mercury and acids. Today in the United Kingdom, there are more than 50 million cell phones that have an average life of two years. To follow the consuming trend, Sims Metal Management offers an electronic waste recycling service for PCs and cell phones, but also for white goods such as refrigerators and washing machines.

Electronic waste is loaded on a conveyor where operatives separate batteries and large copper elements. A first reduction process occurs with the electronic waste being shredded into parts not exceeding 100 mm, hence preparing the materials for the secondary process. The material is then dropped on a hopper to evenly spread it across the width of the conveyor belt. This avoids having agglomerates of materials before entering the recycling machines. The materials go through another shredder to further reduce their size. This step is very polluting and dust is captured with a wind turbine. While still on the conveyor belt, the ferrous and nonferrous elements are separated with a large magnet, as previously described. The material is now composed of nonferrous elements and plastic. Even if deemed nonferrous, the material still has a marginal share of elements responding to magnetic fields. The material goes through an Eddy current (by alternating magnetic fields) and is separated between nonferrous and plastics. The separated material can now be resold to smelters.

The Future of Recycling?

The UK operations of SIMS Metal Management were acquired in 2002. Figure 3.18 highlights the company's profits which are linked to the efficiency of their operations, whilst Figure 3.19 underlines a constant revenue increase through acquisitions. Due to external growth with series of acquisitions, there are disparities across the organization across several continents, for example SIMS Metal in the USA has facilities to specifically recycle aerospace metals.

Also the management of electronic waste is different from one continent from another. For example in the UK, the European Union directives prevail whereas in the USA, it is still regulated by federal laws, not mentioning the differences in electronic waste legislation between the USA and Europe. With a global recycling network and taking advantage of its specialized facilities, SIMS Metal could open the door to specialized recycling, with countries giving advantage to certain types of recycling, as it has happened in manufacturing during the last 30 years.

QUESTIONS

1. Why do the operations of Sims Metal Management impact their ability to offer competitive prices for nonferrous metals?
2. Select a recycling cycle from SIMS Metal and draw its flow chart diagram.
3. Illustrate the evolution of the global supply chain of ferrous metals in the past decade.
4. Discuss the future challenges for Sims Metal Management.

Source: This case was prepared by Xavier Pierron for in-class discussion at Coventry Business School, Coventry, UK. *Annual Reports* (2011) Sims Metal Management, http://www.simsmm.com/news—reports/annual-reports/, last accessed October 30, 2011. *UK Sims Metal Management* (2011) Sims Metal Management, http://uk.simsmm.com/, last accessed October 30, 2011.

CASE José's Authentic Mexican Restaurant

"Two bean tacos, a chicken burrito grande, and a side order of Spanish rice, please." Ivan Karetski called his table's order into the kitchen as he prepared the beverage orders. Business was brisk. Karetski liked it that way. Lots of customers meant lots of tips and, as a struggling graduate student, the extra income was greatly appreciated. Lately, however, his tips had been declining.

José's is a small, 58-seat restaurant that offers a reasonably broad range of Mexican food prepared and presented in a traditional Mexican style. It is located in New England in a mature business district on the edge of a large metropolitan area. The site is adjacent to a central artery and offers limited free off-street parking. The restaurant's interior decoration promotes the Mexican theme: The walls appear to be made of adobe and are draped with serapes, the furniture is Spanish–Mexican style, and flamenco guitar and mariachi alternate as background music.

Patrons enter the restaurant through a small vestibule that opens directly into the dining area; there is no separate waiting area. Upon arrival, patrons are greeted by a hostess and either seated directly or apprised of the expected wait. Seating at José's is usually immediate except for Friday and Saturday nights when waits of as long as 45 minutes can be encountered. Because space inside for waiting is very limited, patrons must remain outside until their party is called. José's does not take reservations.

After seating patrons, the hostess distributes menus and fills glasses with water. If standards are being met, the waiter assigned to the table greets the patrons within one minute of their being seated. (Being a traditional Mexican restaurant, its entire wait staff is male.) The waiter introduces himself, announces the daily specials, and takes the beverage orders. After delivering the beverages, the waiter takes the meal orders.

The menu consists of 23 main entrees assembled from eight basic stocks (chicken, beef, beans, rice, corn tortillas, flour tortillas, tomatoes, and lettuce) and a variety of other ingredients (fruits, vegetables, sauces, herbs, and spices). Before the dining hours begin, the cook prepares the basic stocks so that they can be quickly combined and finished off to complete the requested meals. The typical amount of time needed to complete a meal once it has been ordered is 12 minutes. A good portion of this time is for final cooking, so several meals may be in preparation at the same time. As can be imagined, one of the skills a good cook needs is to be able to schedule production of the various meals ordered at a table so that they are ready at approximately the same time. Once all the meals and any side dishes have been completed by the cook, the waiter checks to see that all meals are correct and pleasing to the eye, corrects any mistakes, and adds any finishing touches. When everything is in order, he assembles them on a tray and delivers them to the table. From this point on, the waiter keeps an eye on the table to detect when any additional service or assistance is needed.

When the diners at the table appear to be substantially finished with their main meal, the waiter approaches, asks if he can clear away any dishes, and takes any requests for dessert or coffee. When the entire meal has been completed, the waiter presents the bill and shortly thereafter collects payment. José's accepts cash or major credit card but no checks.

Karetski feels that his relationship with the cook is important. As the cook largely controls the quality of the food, Karetski wants to stay on good terms with him. He treats the cook with respect, tries to place the items on his order slip in the sequence of longest preparation time, and makes sure to write clearly so that the orders are easy to read. Although it is not his job, he helps out by fetching food stocks from the refrigerator or the storage area when the cook is busy and by doing some of the food preparation himself. The cook has been irritable lately, complaining of the poor quality of some of the ingredients that have been delivered. Last week, for example, he received lettuce that appeared wilted and chicken that was tough and more bone than meat. During peak times, it can take more than 20 minutes to get good meals delivered to the table.

Karetski had been shown the results of a customer survey that management conducted last Friday and Saturday during the evening mealtime. The following table shows a summary of the responses:

Customer Survey Results		
Were you seated promptly?	Yes: 70	No: 13
Was your waiter satisfactory?	Yes: 73	No: 10
Were you served in a reasonable time?	Yes: 58	No: 25
Was your food enjoyable?	Yes: 72	No: 11
Was your dining experience worth the cost?	Yes: 67	No: 16

As Karetski carried the tray of drinks to the table, he wondered whether the recent falloff in tips was due to anything that he could control.

QUESTIONS

1. How should process outcomes and quality be defined at this restaurant?
2. What are the restaurant's costs of process failures?
3. Use some of the tools for process analysis to assess the situation at José's.

Source: This case was prepared by Larry Meile, Boston College, as a basis for classroom discussion. Reprinted by permission.

David J. Green/Alamy

A customer buying from QVC shopping TV channel.

3

MANAGING QUALITY

QVC

Quality and performance is everyone's concern at QVC Inc., one of the largest multimedia retailers in the world. Headquartered in Pennsylvania since 1986, its name is a short form for its customer-focused principles of Quality, Value, and Convenience (QVC). Well prepared hosts, who thoroughly research and understand every product, showcase more than 1000 products per week, with a quarter of them being new ones on a weekly basis. Using some of the most technologically advanced studios, QVC airs 24 hours a day, seven days a week, all year round in the United States, UK, Italy, Japan, Germany, and China. It sells a variety of items ranging from jewelry, tools, cookware, beauty products, apparel, and accessories to electronics. In 2013, QVC shipped more than 169 million products worldwide.

QVC's processes, which span all the functional areas, spring into action with a customer order: Order taking and delivery date promising, billing, and order delivery all ensue once an order is placed. In the United States, QVC operates three call centers in Virginia, Florida, and Texas that handle hundreds of million calls annually from customers who want to order something, complain about a problem, or just get product information. In-house representatives who answer customer calls have an average of seven years of in-house QVC experience. The call center representative's demeanor and skill are critical to achieving a successful customer encounter. QVC management keeps track of productivity, quality, and customer satisfaction measures for all processes. When the measures slip, problems are addressed aggressively. As a result, QVC has achieved a customer satisfaction rating of 95 percent and has been recognized as a top 10 retailer for customer service. Knowing how to assess whether the process is performing well and when to take action are key skills QVC managers must have.

QVC's relentless focus on quality and exceeding customer expectations by placing them at the center of its business processes has paid off handsomely. Either through its on-air programming, mobile platforms, or QVC.com shopping website, it reaches nearly 300 million homes worldwide, with about 100 million of them in the United States alone. With a workforce of 17,000 employees across six countries and revenues in excess of $8.6 billion in 2013, QVC is one of the top mass merchandize retailers globally.

Sources: Anne Schwarz, "Listening to the Voice of the Customer is the Key to QVC's Success," *Journal of Organizational Excellence* (Winter 2004), pp. 3–11; **http://en.wikipedia.org/wiki/Qvc**; **http://www.qvc.com/AboutQVCFacts.content.html** (August 6, 2014).

LEARNING GOALS *After reading this chapter, you should be able to:*

1. Define the four major costs of quality, and their relationship to the role of ethics in determining the overall costs of delivering products and services.
2. Explain the basic principles of Total Quality Management (TQM) and Six Sigma.
3. Understand how acceptance sampling and process performance approaches interface in a supply chain.
4. Describe how to construct process control charts and use them to determine whether a process is out of statistical control.
5. Explain how to determine whether a process is capable of producing a service or product to specifications.
6. Describe International Quality Documentation Standards and the Baldridge Performance Excellence Program.

Using Operations to Create Value

PROCESS MANAGEMENT

Process Strategy and Analysis
→ **Managing Quality**
Planning Capacity
Managing Process Constraints
Designing Lean Systems
Managing Effective Projects

CUSTOMER DEMAND MANAGEMENT

Forecasting Demand
Managing Inventories
Planning and Scheduling Operations
Efficient Resource Planning

SUPPLY CHAIN MANAGEMENT

Designing Effective Supply Chains
Supply Chains and Logistics
Integrating the Supply Chain
Managing Supply Chain Sustainability

The challenge for businesses today is to satisfy their customers through the exceptional performance of their processes. QVC is one example of a company that met the challenge by designing and managing processes that provide customers with total satisfaction. Evaluating process performance is important if this is to happen.

Evaluating process performance is also necessary for managing supply chains. Take for example the telecommunications giant AT&T, which delivers phone, Internet, and cellular data service to millions of commercial and residential customers around the globe. At AT&T, the process of delivering cell phone communications to the customer might be measured on the consistency of service and the sound quality of the voice transmissions. The procurement process, which involves selecting the suppliers for the cell phones and evaluating how they deliver their products, might be measured in terms of the quality of the cell phones delivered to AT&T, the on-time delivery performance of the suppliers, and the cost of the cell phones. Ultimately, the evaluation of the supply chain consisting of these two processes and many others will depend on how well it satisfies the customers of AT&T, who consider the value of the service to be how well it meets or exceeds expectations. The performance of these individual processes must be consistent with the performance measures for the supply chain.

Quality and performance should be everybody's concern. Therefore in this chapter, we first address the costs of quality and then focus on Total Quality Management and Six Sigma, two philosophies and supporting tools that many companies embrace to evaluate and improve quality and performance. We subsequently describe how acceptance sampling and process performance approaches interface in a supply chain, and the role played by process variation in determining whether a process is in statistical control or not. We finally conclude with techniques that can be used to measure and improve quality such that the product or service meets the customers' needs and specifications.

Costs of Quality

defect
Any instance when a process fails to satisfy its customer.

When a process fails to satisfy a customer, the failure is considered a **defect**. For example, according to the California Academy of Family Physicians, defects for the processes in a doctor's practice are defined as "anything that happened in my office that should not have happened, and that I absolutely do not want to happen again." Obviously, this definition covers process failures that the patient sees, such as poor communication and errors in prescription dosages. It also includes failures the patient does not see, such as incorrect charting.

Closely tied to the notion of defects is the question of determining how much quality is enough. There is a greater societal effect that also must be factored into decision making involving the production of services or products that often requires balancing the costs of quality with the overall benefits to society. For example, in the health care industry, aiming for zero complications in cardiac surgery might sound good; however, if it comes at the cost of turning down high-risk patients, is society being served in the best way? Or how much time, energy, and money should go into delivering vaccines or preventing complications? These are questions that often do not have clear answers.

Many companies spend significant time, effort, and expense on systems, training, and organizational changes to improve the quality and performance of their processes. They believe that it is important to be able to gauge current levels of performance so that any process gaps can be determined. Gaps reflect potential dissatisfied customers and additional costs for the firm. Most experts estimate that the costs of quality range from 20 to 30 percent of gross sales. These costs can be broken down into four major categories: (1) prevention, (2) appraisal, (3) internal failure, and (4) external failure. In addition, there is a fifth category of costs associated with unethical behavior in making quality decisions, and which can be significantly higher than all the other four costs combined.

Prevention Costs

Prevention costs are associated with preventing defects before they happen. They include the costs of redesigning the process to remove the causes of poor performance, redesigning the service or product to make it simpler to produce, training employees in the methods of continuous improvement, and working with suppliers to increase the quality of purchased items or contracted services. To prevent problems from happening, firms must invest additional time, effort, and money.

prevention costs
Costs associated with preventing defects before they happen.

Appraisal Costs

Appraisal costs are incurred when the firm assesses the level of performance of its processes. As the costs of prevention increase and performance improves, appraisal costs decrease because fewer resources are needed for quality inspections and the subsequent search for causes of any problems that are detected.

appraisal costs
Costs incurred when the firm assess the performance level of its processes.

Internal Failure Costs

Internal failure costs result from defects that are discovered during the production of a service or product. Defects fall into two main categories: (1) *rework*, which is incurred if some aspect of a service must be performed again or if a defective item must be rerouted to some previous operation(s) to correct the defect; and (2) *scrap*, which is incurred if a defective item is unfit for further processing. For example, an analysis of the viability of acquiring a company might be sent back to the mergers and acquisitions department if an assessment of the company's history of environmental compliance is missing. The proposal for the purchase of the company may be delayed, which may result in the loss of the purchase opportunity.

internal failure costs
Costs resulting from defects that are discovered during the production of a service or product.

External Failure Costs

External failure costs arise when a defect is discovered after the customer receives the service or product. Dissatisfied customers talk about bad service or products to their friends, who in turn tell others. If the problem is bad enough, consumer protection groups may even alert the media. The potential impact on future profits is difficult to assess, but without doubt external failure costs erode market share and profits. Encountering defects and correcting them after the product is in the customer's hands is costly.

External failure costs also include warranty service and litigation costs. A **warranty** is a written guarantee that the producer will replace or repair defective parts or perform the service to the customer's satisfaction. Usually, a warranty is given for some specified period. For example, television repairs are usually guaranteed for 90 days and new automobiles for five years or 50,000 miles, whichever comes first. Warranty costs must be considered in the design of new services or products.

external failure costs
Costs that arise when a defect is discovered after the customer receives the service or product.

warranty
A written guarantee that the producer will replace or repair defective parts or perform the service to the customer's satisfaction.

Ethical Failure Costs

The costs of quality go far beyond the out-of-pocket costs associated with training, appraisal, scrap, rework, warranties, litigation, or the lost sales from dissatisfied customers. **Ethical failure costs** are the societal and monetary costs associated with *deceptively* passing defective services or products to internal or external customers such that it jeopardizes the well-being of stockholders, customers, employees, partners, and creditors.

ethical failure costs
Societal and monetary costs associated with *deceptively* passing defective services or products to internal or external customers such that it jeopardizes the well being of stockholders, customers, employees, partners, and creditors.

Imaginechina/Corbis

A young boy plays with Fisher-Price toys of Mattel at a store in Shanghai.

As a practical matter, ethical costs arise from internal or external failures. The main difference is that somebody tries to "cover them up" and knowingly passes the defects along to the customer knowing that they can do harm. What makes the nature of ethical failure costs different from internal failure or external failure costs already mentioned is the punitive costs of litigation once the ethical lapses are discovered, the extraordinary magnitude of the fines and penalties, the loss of goodwill that can literally damage the firm for a long time, and the hidden costs of employee morale and attitude. Ethical costs are tied to deception and shifting the blame to other partners in the supply chain and go beyond the internal or external failure costs associated with fixing the quality problems in an organization. Mattel, with brands like Fisher Price, Barbie Dolls, and Hot Wheels among others, had to issue multiple product recalls in 2007 due to the presence of cheaper but toxic lead paint in its toys. Problems also existed with loosely attached small magnets in its toys, which if swallowed could cause injuries to the children. Despite exerting downward pressures on costs, Mattel initially denied knowledge and responsibility for the use of lead paint, and instead placed the blame on the suppliers to its manufacturing plants in China. But later on, after stockholder lawsuits claiming the withholding of timely information and misleading financial statements, and also government and media pressure, Mattel instituted stringent inspection and quality programs to prevent the recurrence of such incidents. As a result, Mattel has significantly repaired its corporate image over time.

total quality management (TQM)

A philosophy that stresses three principles for achieving high levels of process performance and quality: (1) customer satisfaction, (2) employee involvement, and (3) continuous improvement in performance.

Deceptive business practices are a source of major concern for service or product quality. Deceptive business practice involves three elements: (1) the conduct of the provider is intentional and motivated by a desire to exploit the customer; (2) the provider conceals the truth based upon what is actually known to the provider; and (3) the transaction is intended to generate a disproportionate economic benefit to the provider at the expense of the customer. This behavior is unethical, diminishes the quality of the customers' experience, and may impose a substantial cost on society. Quality is all about increasing the satisfaction of customers. When a firm engages in unethical behavior and the customer finds out about it, the customer is unlikely to favorably assess the quality of his or her experience with that firm or to return as a customer. Under these conditions, employees of firms that attempt to profit by deceiving customers are less likely to be motivated to put forth their best effort to create true value for customers; they erode a firm's ability to compete now and in the future. Therefore ethical behavior falls on the shoulders of all employees of an organization.

Overall, management must put in place the appropriate processes and approaches to manage the quality costs of prevention, assessment, internal failure, external failure, and ethical failure. Developing the cultural environment for ethical behavior is not cost-free. Employees must be educated in how ethics interfaces with their jobs. The firm may organize an ethics task force or an ethics public relations group to provide an interface between the firm and society. Documentation may be required.

▲ FIGURE 3.1
TQM Wheel

Total Quality Management and Six Sigma

We now turn to a discussion of Total Quality Management and Six Sigma, two philosophies companies use to evaluate and improve quality and process performance along technical, service, and ethical dimensions.

Total Quality Management

Total quality management (TQM) is a philosophy that stresses three principles for achieving high levels of process performance and quality. These principles are related to (1) customer satisfaction, (2) employee involvement, and (3) continuous improvement in performance. As Figure 3.1 indicates, TQM also involves a number of other important elements. We have covered tools and process analysis techniques useful for process problem solving, redesign, and improvement in Chapter 2. Service or product design and purchasing are covered later in this text. Here, we just focus on the three main principles of TQM.

Customer Satisfaction Customers, internal or external, are satisfied when their expectations regarding a service or product have been met or exceeded. Often, customers use the general term **quality** to describe their level of satisfaction with a service or product. Quality has multiple dimensions in the mind of the customer, which cut across the nine competitive priorities we introduced in Chapter 1, "Using Operations to Create Value." One or more of the following five definitions apply at any one time.

quality
A term used by customers to describe their general satisfaction with a service or product.

- **Conformance to Specifications** Although customers evaluate the service or product they receive, it is the processes that produced the service or product that are really being judged. In this case, a process failure would be the process's inability to meet certain advertised or implied performance standards. Conformance to specifications may relate to consistent quality, on-time delivery, or delivery speed.
- **Value** Another way customers define quality is through value, or how well the service or product serves its intended purpose at a price customers are willing to pay. The service or product development process plays a role here, as do the firm's competitive priorities relating to top quality versus low-cost operations. The two factors must be balanced to produce value for the customer. How much value a service or product has in the mind of the customer depends on the customer's expectations before purchasing it.
- **Fitness for Use** When assessing how well a service or product performs its intended purpose, the customer may consider the convenience of a service, the mechanical features of a product, or other aspects such as appearance, style, durability, reliability, craftsmanship, and serviceability. For example, you may define the quality of the entertainment center you purchased on the basis of how easy it was to assemble and its appearance and styling.
- **Support** Often the service or product support provided by the company is as important to customers as the quality of the service or product itself. Customers get upset with a company if its financial statements are incorrect, responses to its warranty claims are delayed, its advertising is misleading, or its employees are not helpful when problems are incurred. Good support once the sale has been made can reduce the consequences of quality failures.
- **Psychological Impressions** People often evaluate the quality of a service or product on the basis of psychological impressions: atmosphere, image, or aesthetics. In the provision of services where the customer is in close contact with the provider, the appearance and actions of the provider are especially important. Nicely dressed, courteous, friendly, and sympathetic employees can affect the customer's perception of service quality.

Attaining quality in all areas of a business is a difficult task. To make things even more difficult, consumers change their perceptions of quality. In general, a business's success depends on the accuracy of its perceptions of consumer expectations and its ability to bridge the gap between those expectations and operating capabilities. Good quality pays off in higher profits. High-quality services and products can be priced higher and yield a greater return. Poor quality erodes the firm's ability to compete in the marketplace and increases the costs of producing its service or product. Managerial Practice 3.1 shows how Verizon Wireless aims to improve customer satisfaction by emphasizing many of the quality dimensions outlined above.

Employee Involvement One of the important elements of TQM is employee involvement, as shown in Figure 3.1. A program in employee involvement includes changing organizational culture and encouraging teamwork.

- **Cultural Change** One of the main challenges in developing the proper culture for TQM is to define *customer* for each employee. In general, customers are internal or external. *External customers* are the people or firms who buy the service or product. Some employees, especially those having little contact with external customers, may have difficulty seeing how their jobs contribute to the whole effort.

  It is helpful to point out to employees that each employee also has one or more *internal customers*—employees in the firm who rely on the output of other employees. All employees must do a good job of serving their internal customers if external customers ultimately are to be satisfied. They will be satisfied only if each internal customer demands value be added that the external customer will recognize and pay for. The notion of internal customers applies to all parts of a firm and enhances cross-functional coordination. For example, accounting must prepare accurate and

MANAGERIAL PRACTICE 3.1 Quality at Verizon Wireless

Anyone who owns a cell phone knows the agony of a dropped call. Did you know that the reason for the dropped call may be the phone itself and not the strength of the signal? With annual revenues of $81 billion and 74,000 employees in 2013, Verizon Wireless serves more than 105 million retail connections in the United States. Along with the other major carriers, it knows that if the phone does not work, the company, and not the manufacturer, will likely take the blame from the customer. With major investments in its technologically advanced 4G-LTE networks in the United States, Verizon touts the reliability of its services and can ill afford the failure of cell phones due to the quality of manufacture. Verizon expects manufacturers such as Motorola, Apple, Samsung, and LG Electronics to provide defect-free phones; however, experience has indicated that extensive testing by Verizon employees is also needed.

In addition to a tear-down analysis that looks for weaknesses in a phone's hardware and components, the device is tested for its ability to withstand temperature extremes, vibration, and stress. Beyond these physical tests, Verizon uses two approaches to assess a phone's capability to receive cellular signals and clearly communicate to the caller. First, Verizon hires 98 test personnel who drive $300,000 specially equipped vans more than 1 million miles a year to measure network performance using prospective new cell phones. They make more than 3 million voice call attempts and 16 million data tests annually. The tests check the coverage of the network as well as the capability of the cell phones to pick up the signals and clearly communicate to the caller. Second, Verizon uses Mr. Head, a robotic mannequin, who has a recorded voice and is electronically equipped with a rubber ear that evaluates how well the phone's mouthpiece transmits certain phonetics. Mr. Head utters what sounds like gibberish; however, it actually covers the range of sounds in normal speech patterns. Other systems monitor the tests and summarize results. Some phones spend so much time in the test phase that ultimately they never make it to the market. Clearly, in those cases, the cost of poor quality to the manufacturer is very high.

Along with testing the quality of its hardware and wireless service, Verizon also provides extensive training to its customer service representatives. Quality checks are done through company executives visiting retail stores and each of its 34 customer service center operations. With its focus on quality in operations, products, services, and technology, it is not surprising that Verizon Wireless has built a great reputation with its customer base and has also been recognized through several best wireless service awards.

ZUMA Press/Newscom

A baseline technician for Verizon Wireless checks boxes of cell phones wired to his computer used to check reception in different areas and also competition's reception and signal as he drives about Sacramento territory.

Sources: Amol Sharma, "Testing, Testing," *Wall Street Journal* (October 23, 2007); Janet Hefler, "Verizon Tester Checks Vineyard Networks," *The Martha's Vineyard Times* (August 30, 2007); Jon Gales, "Ride Along With a Verizon Wireless Test Man," *Mobile Tracker* (April 4, 2005); **http://www.verizonwireless.com/aboutus/company/story.html** (August 6, 2014).

quality at the source
A philosophy whereby defects are caught and corrected where they were created.

teams
Small groups of people who have a common purpose, set their own performance goals and approaches, and hold themselves accountable for success.

employee empowerment
An approach to teamwork that moves responsibility for decisions further down the organizational chart—to the level of the employee actually doing the job.

timely reports for management, and purchasing must provide high-quality materials on time for operations.

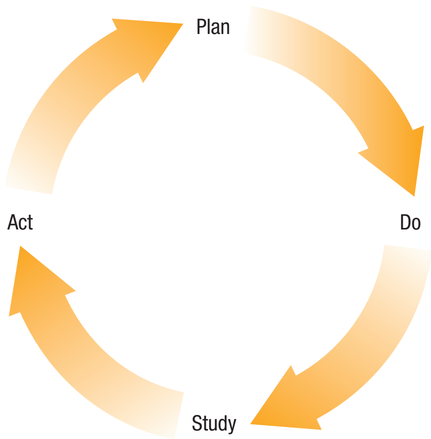
In TQM, everyone in the organization must share the view that quality control is an end in itself. Errors or defects should be caught and corrected at the source, not passed along to an internal or external customer. For example, a consulting team should make sure its billable hours are correct before submitting them to the accounting department. This philosophy is called **quality at the source**. In addition, firms should avoid trying to "inspect quality into the product" by using inspectors to weed out unsatisfactory services or defective products after all operations have been performed. By contrast, in some manufacturing firms, workers have the authority to stop a production line if they spot quality problems.

- **Teams** Employee involvement is a key tactic for improving processes and quality. One way to achieve employee involvement is by the use of **teams**, which are small groups of people who have a common purpose, set their own performance goals and approaches, and hold themselves accountable for success. The three approaches to teamwork most often used are (1) problem-solving teams, (2) special-purpose teams, and (3) self-managed teams. All three use some amount of **employee**

empowerment, which moves responsibility for decisions further down the organizational chart—to the level of the employee actually doing the job.

Continuous Improvement Based on a Japanese concept called *kaizen*, **continuous improvement** is the philosophy of continually seeking ways to improve processes. Continuous improvement involves identifying benchmarks of excellent practice and instilling a sense of employee ownership in the process. The focus of continuous improvement projects is to reduce waste, such as reducing the length of time required to process requests for loans at a bank, the amount of scrap generated at a milling machine, or the number of employee injuries at a construction site. The basis of the continuous improvement philosophy is the belief that virtually any aspect of a process can be improved and that the people most closely associated with a process are in the best position to identify the changes that should be made. The idea is not to wait until a massive problem occurs before acting.

Employees should be given problem-solving tools, such as the statistical process control (SPC) methods we discuss later in this chapter, and a sense of ownership of the process to be improved. A sense of operator ownership emerges when employees feel a responsibility for the processes and methods they use and take pride in the quality of the service or product they produce. It comes from participation on work teams and in problem-solving activities, which instill in employees a feeling that they have some control over their workplace and tasks.



▲ **FIGURE 3.2**
Plan-Do-Study-Act Cycle

continuous improvement

The philosophy of continually seeking ways to improve processes based on a Japanese concept called *kaizen*.

Most firms actively engaged in continuous improvement train their work teams to use the **plan-do-study-act cycle** for problem solving. Another name for this approach is the Deming Wheel, named after the renowned statistician W. Edwards Deming who taught quality improvement techniques to the Japanese after World War II. Figure 3.2 shows this cycle, which lies at the heart of the continuous improvement philosophy. The cycle comprises the following steps:

plan-do-study-act cycle

A cycle, also called the Deming Wheel, used by firms actively engaged in continuous improvement to train their work teams in problem solving.

1. *Plan.* The team selects a process (an activity, method, machine, or policy) that needs improvement. The team then documents the selected process, usually by analyzing related data; sets qualitative goals for improvement; and discusses various ways to achieve the goals. After assessing the benefits and costs of the alternatives, the team develops a plan with quantifiable measures for improvement.
2. *Do.* The team implements the plan and monitors progress. Data are collected continuously to measure the improvements in the process. Any changes in the process are documented, and further revisions are made as needed.
3. *Study.* The team analyzes the data collected during the *do* step to find out how closely the results correspond to the goals set in the *plan* step. If major shortcomings exist, the team reevaluates the plan or stops the project.
4. *Act.* If the results are successful, the team documents the revised process so that it becomes the standard procedure for all who may use it. The team may then instruct other employees in the use of the revised process.

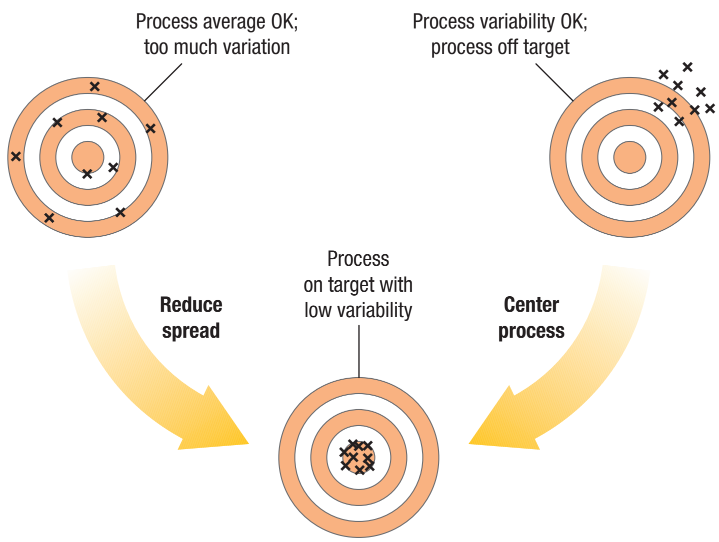
Six Sigma

A comprehensive and flexible system for achieving, sustaining, and maximizing business success by minimizing defects and variability in processes.

Problem-solving projects often focus on those aspects of processes that do not add value to the service or product. Value is added in processes such as machining a part or serving a customer through a Web page. No value is added in activities such as inspecting parts for defects or routing requests for loan approvals to several different departments. The idea of continuous improvement is to reduce or eliminate activities that do not add value and, thus, are wasteful.

MyOMLab Animation

▼ **FIGURE 3.3**
Six Sigma Approach Focuses on Reducing Spread and Centering the Process



Six Sigma

Six Sigma, which relies heavily on the principles of TQM, is a comprehensive and flexible system for achieving, sustaining, and maximizing business success by minimizing defects and variability in processes. Six Sigma has a different focus than TQM: It is driven by a close understanding of customer needs; the disciplined use of facts, data, and statistical analysis; and diligent attention to managing, improving, and reinventing business processes. Figure 3.3 shows how Six Sigma focuses on reducing variation in processes as well as centering processes on their target measures of performance. Either flaw—too much variation or an off-target process—degrades performance of the process. For example, a mortgage loan department of a bank might advertise loan

Rick Friedman/Corbis

Harley Davidson uses Statistical Process Control techniques to enhance the quality of its motorcycles in different areas of the plant where the motorcycles are assembled.

approval decisions in two days. If the actual performance ranges from one day to five days, with an average of two days, those customers who had to wait longer than two days would be upset. Process variability causes customer dissatisfaction. Similarly, if actual performance consistently produced loan decisions in three days, all customers would be dissatisfied. In this case, the process is consistent, but off the target. Six Sigma is a rigorous approach to align processes with their target performance measures with low variability.

The name Six Sigma, originally developed by Motorola for its manufacturing operations, relates to the goal of achieving low rates of defective output by developing processes whose mean output for a performance measure is $\pm$ six standard deviations (sigma) from the limits of the design specifications for the service or product. We will discuss variability and its implications on the capability of a process to perform at acceptable levels when we present the tools of statistical process control.

Although Six Sigma was rooted in an effort to improve manufacturing processes, credit General Electric with popularizing the application of the approach to non-manufacturing processes such as sales, human resources, customer service, and financial services. The concept of eliminating defects is the same, although the definition of "defect" depends on the process involved. For example, a human resource department's failure to meet a hiring target counts as a defect. Using the DMAIC approach within the Six Sigma Improvement model highlighted in Chapter 2, "Process Strategy and Analysis," Six Sigma process improvement specialists with black belts have been able to mentor employees and successfully apply Six Sigma to improve a host of service processes, including financial services, human resource processes, marketing processes, and health care administrative processes.

Acceptance Sampling

Before any internal process can be evaluated for performance, the inputs to that process must be of good quality. **Acceptance sampling**, which is the application of statistical techniques to determine if a quantity of material from a supplier should be accepted or rejected based on the inspection or test of one or more samples, limits the buyer's risk of rejecting good-quality materials (and unnecessarily delaying the production of goods or services) or accepting bad-quality materials (and incurring downtime due to defective materials or passing bad products to customers). Relative to the specifications for the material the buyer is purchasing, the buyer specifies an **acceptable quality level (AQL)**, which is a statement of the proportion of defective items (outside of specifications) that the buyer will accept in a shipment. These days, that proportion is getting very small, often measured in parts per ten-thousand. The idea of acceptance sampling is to take a sample, rather than testing the entire quantity of material, because that is often less expensive. Therein lies the risk—the sample may not be representative of the entire lot of goods from the supplier. The basic procedure is straightforward.

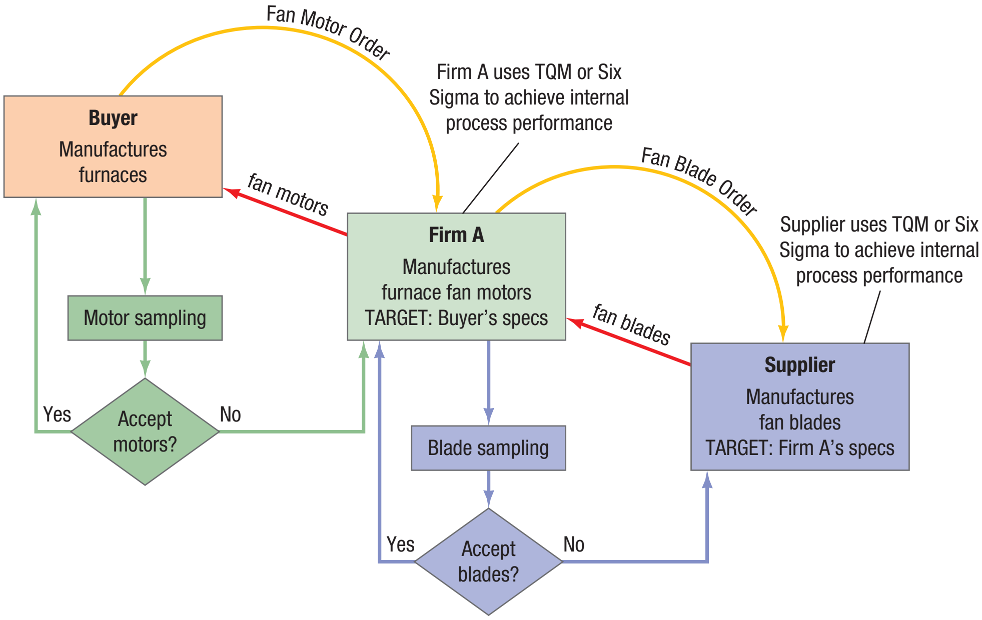
Ian Shaw/Alamy

Wine production is an example of a situation where complete inspection is not an option. Here a quality inspector draws a sample of white wine from a stainless steel maturation tank.

1. A random sample is taken from a large quantity of items and tested or measured relative to the specifications or quality measures of interest.
2. If the sample passes the test (low number of defects), the entire quantity of items is accepted.
3. If the sample fails the test, either (a) the entire quantity of items is subjected to 100 percent inspection and all defective items repaired or replaced or (b) the entire quantity is returned to the supplier.

In a supply chain, any company can be both a producer of goods purchased by another company and a consumer of goods or raw materials supplied by another company. Figure 3.4 shows a flowchart of how acceptance sampling and internal process performance (TQM or Six Sigma) interface in a supply chain. From the perspective of the supply chain, the buyer's specifications for various dimensions of quality become the targets the supplier shoots for in a supply contract. The supplier's internal processes must be up to the task; TQM or Six Sigma can help achieve the desired performance. The buyer's sampling plan will provide a high probability of accepting AQL (or better). MyOMLab Supplement G, "Acceptance Sampling

Plans," shows how to design an acceptance sampling plan that meets the level of risk desired.



▲ **FIGURE 3.4**
Interface of Acceptance Sampling and Process Performance Approaches in a Supply Chain

MyOMLab Animation

Statistical Process Control

Regardless of whether a firm is producing a service or a product, it is important to ensure that the firm's processes are providing the quality that customers want. A key element of TQM or Six Sigma is building the capability to monitor the performance of processes so that corrective action can be initiated in a timely fashion. Evaluating the performance of processes requires a variety of data gathering approaches. We already discussed checklists, histograms and bar charts, Pareto charts, scatter diagrams, cause-and-effect diagrams, and graphs (see Chapter 2, "Process Strategy and Analysis"). All of these tools can be used with TQM or Six Sigma. Here, we focus on the powerful statistical tools that can be used to monitor and manage repetitive processes.

Statistical process control (SPC) is the application of statistical techniques to determine whether a process is delivering what customers want. In SPC, tools called control charts are used primarily to detect defective services or products or to indicate that the process has changed and that services or products will deviate from their design specifications, unless something is done to correct the situation. SPC can also be used to inform management of improved process changes. Examples of process changes that can be detected by SPC include the following:

- A decrease in the average number of complaints per day at a hotel
- A sudden increase in the proportion of defective gear boxes
- An increase in the time to process a mortgage application
- A decline in the number of scrapped units at a milling machine
- An increase in the number of claimants receiving late payment from an insurance company

Let us consider the last situation. Suppose that the manager of the accounts payable department of an insurance company notices that the proportion of claimants receiving late payments rose from an average of 0.01 to 0.03. The first question is whether the rise is a cause for alarm or just a random occurrence. Statistical process control can help the manager decide whether further action should be taken. If the rise in the proportion is not just a random occurrence, the manager should seek explanations of the poor performance. Perhaps the number of claims significantly increased causing an overload on the employees in the department. The decision might be to hire more personnel. Or perhaps the procedures being used are ineffective or the training of employees is inadequate. SPC is an integral part of TQM and Six Sigma.

acceptance sampling
The application of statistical techniques to determine whether a quantity of material should be accepted or rejected based on the inspection or test of a sample.

acceptable quality level (AQL)
The quality level desired by the consumer.

statistical process control (SPC)
The application of statistical techniques to determine whether a process is delivering what the customer wants.

Variation of Outputs

No two services or products are exactly alike because the processes used to produce them contain many sources of variation, even if the processes are working as intended. Nonetheless, it is important to minimize the variation in outputs because frequently variation is what the customer sees and feels. Suppose a physicians' clinic submits claims on behalf of its patients to a particular insurance company. In this situation, the physicians' clinic is the customer of the insurance company's bill payment process. In some cases, the clinic receives payment in 4 weeks, and in other cases 20 weeks. The time to process a request for payment varies because of the load on the insurance company's processes, the medical history of the patient, and the skills and attitudes of the employees. Meanwhile, the clinic must cover its expenses while it waits for payment. Regardless of whether the process is producing services or products, nothing can be done to eliminate variation in output completely; however, management should investigate the *causes* of the variation in order to minimize it.

Chuck Rausin/Shutterstock.com

Process measurement is the key to quality improvement. Here a quality inspector measures the diameter of holes in a machined part.

Performance Measurements Performance can be evaluated in two ways. One way is to measure **variables**—that is, service or product characteristics, such as weight, length, volume, or time, that can be *measured*. The advantage of using performance variables is that if a service or product misses its performance specifications, the inspector knows by how much. The disadvantage is that such measurements typically involve special equipment, employee skills, exacting procedures, and time and effort.

Another way to evaluate performance is to measure **attributes**; service or product characteristics that can be quickly *counted* for acceptable performance. This method allows inspectors to make a simple "yes or no" decision about whether a service or product meets the specifications. Attributes often are used when performance specifications are complex and measurement of variables is difficult or costly. Some examples of attributes that can be counted are the number of insurance forms containing errors that cause underpayments or overpayments, the proportion of airline flights arriving within 15 minutes of scheduled times, and the number of stove-top assemblies with spotted paint.

The advantage of counting attributes is that less effort and fewer resources are needed than for measuring variables. The disadvantage is that, even though attribute counts can reveal that process performance has changed, they do not indicate by how much. For example, a count may determine that the proportion of airline flights arriving within 15 minutes of their scheduled times declined, but the result does not show how much beyond the 15-minute allowance the flights are arriving. For that, the actual deviation from the scheduled arrival, a variable, would have to be measured.

Sampling The most thorough approach to inspection is to inspect each service or product at each stage of the process for quality. This method, called *complete inspection*, is used when the costs of passing defects to an internal or external customer outweigh the inspection costs. Firms often use automated inspection equipment that can record, summarize, and display data. Many companies find that automated inspection equipment can pay for itself in a reasonably short time.

A well-conceived **sampling plan** can approach the same degree of protection as complete inspection. A sampling plan specifies a **sample size**, which is a quantity of randomly selected observations of process outputs, the time between successive samples, and decision rules that determine when action should be taken. Sampling is appropriate when inspection costs are high because of the special knowledge, skills, procedures, and expensive equipment that are required to perform the inspections, or because the tests are destructive.

variables

Service or product characteristics, such as weight, length, volume, or time, that can be measured.

attributes

Service or product characteristics that can be quickly counted for acceptable performance.

sampling plan

A plan that specifies a sample size, the time between successive samples, and decision rules that determine when action should be taken.

sample size

A quantity of randomly selected observations of process outputs.

Sampling Distributions Relative to a performance measure, a process will produce output that can be described by a *process distribution*, with a mean and variance that will be known only with a complete inspection with 100 percent accuracy. The purpose of sampling, however, is to estimate a variable or attribute measure for the output of the process without doing a complete inspection. That measure is then used to assess the performance of the process itself. For example, the time required to process specimens at an intensive care unit lab in a hospital (a variable measure) will vary. If you measured the time to complete an analysis of a large number of patients and plotted the results, the data would tend to form a pattern that can be described as a process distribution. With sampling, we try to estimate the parameters of the process distribution using statistics such as the sample mean and the sample range or standard deviation.

1. The *sample mean* is the sum of the observations divided by the total number of observations:

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

where

x_i = observation of a quality characteristic (such as time)

n = total number of observations

$\bar{x}$ = mean

2. The *range* is the difference between the largest observation in a sample and the smallest. The *standard deviation* is the square root of the variance of a distribution. An estimate of the process standard deviation based on a sample is given by

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} \quad \text{or} \quad \sigma = \sqrt{\frac{\sum_{i=1}^{n} x^2 - \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n}}{n-1}}$$

where

σ = standard deviation of a sample

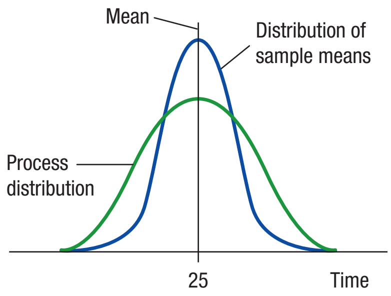
n = total number of observations in the sample

$\bar{x}$ = mean

x_i = observation of a quality characteristic

Relatively small values for the range or the standard deviation imply that the observations are clustered near the mean.

These sample statistics have their own distribution, which we call a *sampling distribution*. For example, in the lab analysis process, an important performance variable is the time it takes to get results to the critical care unit. Suppose that management wants results available in an average of 25 minutes. That is, it wants the process distribution to have a mean of 25 minutes. An inspector periodically taking a sample of five analyses and calculating the sample mean could use it to determine how well the process is doing. Suppose that the process is actually producing the analyses with a mean of 25 minutes. Plotting a large number of these sample means would show that they have their own sampling distribution with a mean centered on 25 minutes, as does the process distribution mean, but with much less variability. The reason is that the sample means offset the highs and lows of the individual times in each sample. Figure 3.5 shows the relationship between the sampling distribution of sample means and the process distribution for the analysis times.



▲ FIGURE 3.5
Relationship Between the Distribution of Sample Means and the Process Distribution

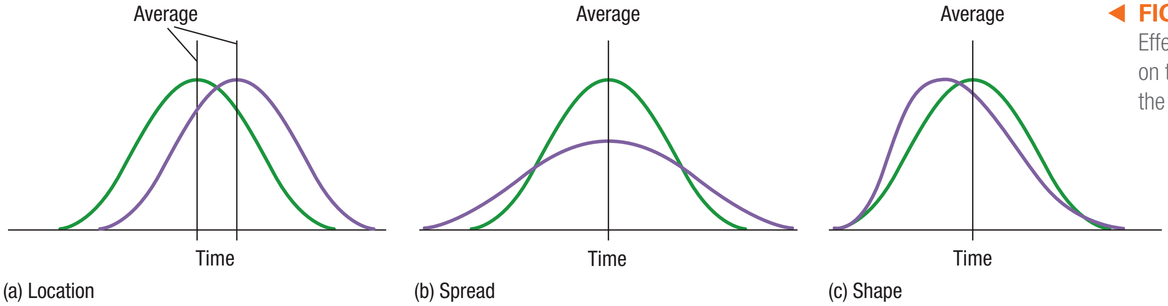
Some sampling distributions (e.g., for means with sample sizes of four or more and proportions with sample sizes of 20 or more) can be approximated by the normal distribution, allowing the use of the normal tables (see Appendix 1, "Normal Distribution"). For example, suppose you wanted to determine the probability that a sample mean will be more than 2.0 standard deviations higher than the process mean. Go to Appendix 1 and note that the entry in the table for $z = 2.0$ standard deviations is 0.9772. Consequently, the probability is $1.0000 - 0.9772 = 0.0228$, or 2.28 percent. The probability that the sample mean will be more than 2.0 standard deviations lower than the process mean is also 2.28 percent because the normal distribution is symmetric to the mean. The ability to assign probabilities to sample results is important for the construction and use of control charts.

Common Causes The two basic categories of variation in output include common causes and assignable causes. **Common causes of variation** are the purely random, unidentifiable sources of variation that are unavoidable with the current process. A process distribution can be characterized by its *location*, *spread*, and *shape*. Location is measured by the *mean* of the distribution, while spread is measured by the *range* or *standard deviation*. The shape of process distributions can be characterized as either symmetric or skewed. A *symmetric* distribution has the same number of observations above and below the mean. A *skewed* distribution has a greater number of observations either above or below the mean. If process variability results solely from common causes of variation, a typical assumption is that the distribution is symmetric, with most observations near the center.

common causes of variation
The purely random, unidentifiable sources of variation that are unavoidable with the current process.

Assignable Causes The second category of variation, **assignable causes of variation**, also known as *special causes*, includes any variation-causing factors that can be identified and eliminated. Assignable causes of variation include an employee needing training or a machine needing repair. Let us return to the example of the lab analysis process. Figure 3.6 shows how assignable causes can change the

assignable causes of variation
Any variation-causing factors that can be identified and eliminated.

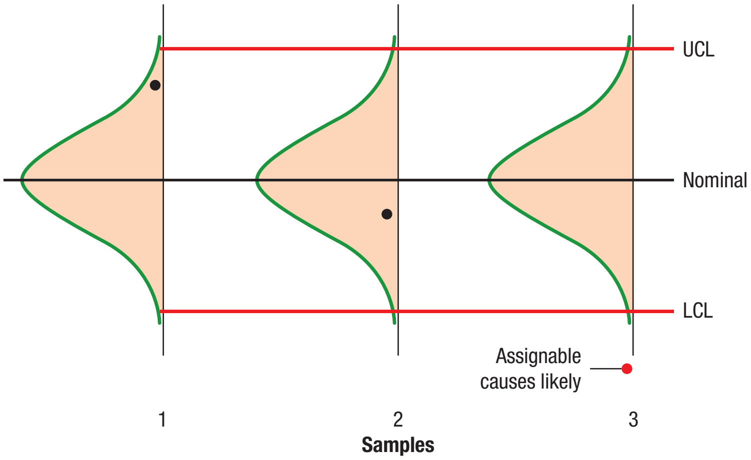


◀ FIGURE 3.6
Effects of Assignable Causes on the Process Distribution for the Lab Analysis Process

distribution of output for the analysis process. The **green** curve is the process distribution when only common causes of variation are present. The **purple** curves depict a change in the distribution because of assignable causes. In Figure 3.6(a), the **purple** curve indicates that the process took more time than planned in many of the cases, thereby increasing the average time of each analysis. In Figure 3.6(b), an increase in the variability of the time for each case affected the spread of the distribution. Finally, in Figure 3.6(c), the **purple** curve indicates that the process produced a preponderance of the tests in less than average time. Such a distribution is skewed, or no longer symmetric to the average value. A process is said to be in statistical control when the location, spread, or shape of its distribution does not change over time. After the process is in statistical control, managers use SPC procedures to detect the onset of assignable causes so that they can be addressed.

control chart

A time-ordered diagram that is used to determine whether observed variations are abnormal.



▲ FIGURE 3.7
How Control Limits Relate to the Sampling Distribution: Observations from Three Samples

MyOMLab Animation

Control Charts

To determine whether observed variations are abnormal, we can measure and plot the performance measure taken from the sample on a time-ordered diagram called a **control chart**. A control chart has a nominal value, or central line, which can be the process's historic average or a target that managers would like the process to achieve, and two control limits based on the sampling distribution of the quality measure. The control limits are used to judge whether action is required. The larger value represents the *upper control limit* (UCL), and the smaller value represents the *lower control limit* (LCL). Figure 3.7 shows how the control limits relate to the sampling distribution. A sample statistic that falls between the UCL and the LCL indicates that the process is exhibiting common causes of variation. A statistic that falls outside the control limits indicates that the process is exhibiting assignable causes of variation.

Observations falling outside the control limits do not always mean poor quality. For example, in Figure 3.7 the assignable cause may be a new billing process introduced to reduce the number of incorrect bills sent to customers. If the proportion of incorrect bills, that is, the performance measure from a sample of bills, falls *below* the LCL of the control chart, the new procedure likely changed the billing process for the better, and a new control chart should be constructed.

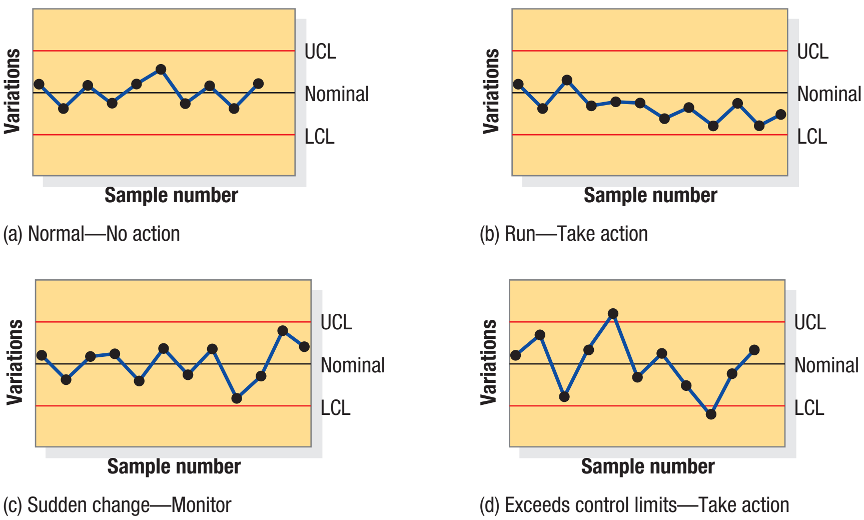
Managers or employees responsible for evaluating a process can use control charts in the following way:

1. Take a random sample from the process and calculate a variable or attribute performance measure.
2. If the statistic falls outside the chart's control limits or exhibits unusual behavior, look for an assignable cause.
3. Eliminate the cause if it degrades performance; incorporate the cause if it improves performance. Reconstruct the control chart with new data.
4. Repeat the procedure periodically.

Sometimes, problems with a process can be detected even though the control limits have not been exceeded. Figure 3.8 contains four examples of control charts. Chart (a) shows a process that is in statistical control. No action is needed. However, chart (b) shows a pattern called a *run* or a sequence of observations with a certain characteristic. A typical rule is to take remedial action when five or more observations show a downward or upward trend, even if the points have not yet exceeded the control limits. Here, nine sequential observations are below the mean and show a downward trend. The probability is low that such a result could take place by chance.

Chart (c) shows that the process takes a sudden change from its normal pattern. The last four observations are unusual: The first drops close to the LCL, the next two rise toward the UCL, and the fourth remains above the nominal value. Managers or employees should monitor processes with such sudden changes even though the control limits have not been exceeded. Finally, chart (d) indicates that the process went out of control twice because two sample results fell outside the

▼ FIGURE 3.8
Control Chart Examples



control limits. The probability that the process distribution has changed is high. We discuss more implications of being out of statistical control when we discuss process capability later in this chapter.

Control charts are not perfect tools for detecting shifts in the process distribution because they are based on sampling distributions. Two types of error are possible with the use of control charts. A **type I error** occurs when the conclusion is made that the process is out of control based on a sample result that falls outside the control limits, when in fact it was due to pure randomness. A **type II error** occurs when the conclusion is that the process is in control and only randomness is present, when actually the process is out of statistical control.

type I error

An error that occurs when the employee concludes that the process is out of control based on a sample result that falls outside the control limits, when in fact it was due to pure randomness.

type II error

An error that occurs when the employee concludes that the process is in control and only randomness is present, when actually the process is out of statistical control.

These errors can be controlled by the choice of control limits. The choice would depend on the costs of looking for assignable causes when none exist versus the cost of not detecting a shift in the process. For example, setting control limits at $\pm$ three standard deviations from the mean reduces the type I error because chances are only 0.26 percent that a sample result will fall outside of the control limits unless the process is out of statistical control. However, the type II error may be significant; more subtle shifts in the nature of the process distribution will go undetected because of the wide spread in the control limits. Alternatively, the spread in the control limits can be reduced to $\pm$ two standard deviations, thereby increasing the likelihood of sample results from a non-faulty process falling outside of the control limits to 4.56 percent. Now, the type II error is smaller, but the type I error is larger because employees are likely to search for assignable causes when the sample result occurred solely by chance. As a general rule, use wider limits when the cost for searching for assignable causes is large relative to the cost of not detecting a shift in the process distribution.

SPC methods are useful for both measuring the current process performance and detecting whether the process has changed in a way that will affect future performance. Consequently, we first discuss mean and range charts for variable measures of performance and then consider control charts for attributes measures.

Control Charts for Variables

Control charts for variables are used to monitor the mean and the variability of the process distribution.

***R*-Chart** A range chart, or ***R*-chart**, is used to monitor process variability. To calculate the range of a set of sample data, the analyst subtracts the smallest from the largest measurement in each sample. If any of the ranges fall outside the control limits, the process variability is not in control.

***R*-chart**

A chart used to monitor process variability.

The control limits for the *R*-chart are

$$\text{UCL}_R = D_4\overline{R} \quad \text{and} \quad \text{LCL}_R = D_3\overline{R}$$

where

$\overline{R}$ = average of several past R values and the central line of the control chart

D_3, D_4 = constants that provide three standard deviation (three-sigma) limits for a given sample size

Notice that the values for D_3 and D_4 shown in Table 3.1 change as a function of the sample size. Notice, too, that the spread between the control limits narrows as the sample size increases. This change is a consequence of having more information on which to base an estimate for the process range.

TABLE 3.1 FACTORS FOR CALCULATING THREE SIGMA LIMITS FOR THE $\bar{x}$-CHART AND *R*-CHART

Size of Sample (n)	Factor for UCL and LCL for $\bar{x}$-Chart (A_2)	Factor for LCL for R-Chart (D_3)	Factor for UCL for R-Chart (D_4)
2	1.880	0	3.267
3	1.023	0	2.575
4	0.729	0	2.282
5	0.577	0	2.115
6	0.483	0	2.004
7	0.419	0.076	1.924
8	0.373	0.136	1.864
9	0.337	0.184	1.816
10	0.308	0.223	1.777

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$\bar{x}$-chart

A chart used to see whether the process is generating output, on average, consistent with a target value set by management for the process or whether its current performance, with respect to the average of the performance measure, is consistent with past performance.

$\bar{x}$-Chart An **$\bar{x}$-Chart** (read "x-bar chart") is used to see whether the process is generating output, on average, consistent with a target value set by management for the process or whether its current performance, with respect to the average of the performance measure, is consistent with its past performance. A target value is useful when a process is completely redesigned and past performance is no longer relevant. When the assignable causes of process variability have been identified and the process variability is in statistical control, the analyst can then construct an $\bar{x}$-chart. The control limits for the $\bar{x}$-chart are

$$\text{UCL}_{\bar{x}} = \bar{\bar{x}} + A_2\bar{R} \quad \text{and} \quad \text{LCL}_{\bar{x}} = \bar{\bar{x}} - A_2\bar{R}$$

where

$\bar{\bar{x}}$ = central line of the chart, which can be either the average of past sample means or a target value set for the process

A_2 = constant to provide three-sigma limits for the sample mean

The values for A_2 are contained in Table 3.1. Note that the control limits use the value of $\bar{R}$; therefore, the $\bar{x}$-chart must be constructed *after* the process variability is in control.

To develop and use $\bar{x}$- and R-charts, do the following:

Step 1. Collect data on the variable quality measurement (such as time, weight, or diameter) and organize the data by sample number. Preferably, at least 20 samples of size n should be taken for use in constructing a control chart.

Lyroky/Alamy

An analyst measures the diameter of a part with a micrometer. After he measures the sample, he plots the range on the control chart.

Step 2. Compute the range for each sample and the average range, $\bar{R}$, for the set of samples.

Step 3. Use Table 3.1 to determine the upper and lower control limits of the R-chart.

Step 4. Plot the sample ranges. If all are in control, proceed to step 5. Otherwise, find the assignable causes, correct them, and return to step 1.

Step 5. Calculate $\bar{x}$ for each sample and determine the central line of the chart, $\bar{\bar{x}}$.

Step 6. Use Table 3.1 to determinew the parameters for $\text{UCL}_{\bar{x}}$ and $\text{LCL}_{\bar{x}}$ and construct the $\bar{x}$-chart.

Step 7. Plot the sample means. If all are in control, the process is in statistical control in terms of the process average and process variability. Continue to take samples and monitor the process. If any are out of control, find the assignable causes, address them, and return to step 1. If no assignable causes are found after a diligent search, assume that the out-of-control points represent common causes of variation and continue to monitor the process.

EXAMPLE 3.1 Using $\bar{x}$ and R-Charts to Monitor a Process

MyOMLab

Tutor 3.1 in MyOMLab provides a new example to practice the use of x-bar and R-charts.

MyOMLab

Active Model 3.1 in MyOMLab provides additional insight on the x-bar and R-charts and their uses for the metal screw problem.

The management of West Allis Industries is concerned about the production of a special metal screw used by several of the company's largest customers. The diameter of the screw is critical to the customers. Data from five samples appear in the accompanying table. The sample size is 4. Is the process in statistical control?

SOLUTION

Step 1. For simplicity, we use only 5 samples. In practice, more than 20 samples would be desirable. The data are shown in the following table.

DATA FOR THE $\bar{x}$- AND R-CHARTS: OBSERVATIONS OF SCREW DIAMETER (INCH)

	OBSERVATIONS					
Sample Number	**1**	**2**	**3**	**4**	**R**	**$\bar{x}$**
1	0.5014	0.5022	0.5009	0.5027	0.0018	0.5018
2	0.5021	0.5041	0.5024	0.5020	0.0021	0.5027
3	0.5018	0.5026	0.5035	0.5023	0.0017	0.5026
4	0.5008	0.5034	0.5024	0.5015	0.0026	0.5020
5	0.5041	0.5056	0.5034	0.5047	0.0022	0.5045
				Average	0.0021	0.5027

Step 2. Compute the range for each sample by subtracting the lowest value from the highest value. For example, in sample 1 the range is $0.5027 - 0.5009 = 0.0018$ inch. Similarly, the ranges for samples 2, 3, 4, and 5 are 0.0021, 0.0017, 0.0026, and 0.0022 inch, respectively. As shown in the table, $\overline{R} = 0.0021$.

Step 3. To construct the *R*-chart, select the appropriate constants from Table 3.1 for a sample size of 4. The control limits are

$$\text{UCL}_R = D_4\overline{R} = 2.282(0.0021) = 0.00479 \text{ inch}$$

$$\text{LCL}_R = D_3\overline{R} = 0(0.0021) = 0 \text{ inch}$$

Step 4. Plot the ranges on the R-chart, as shown in Figure 3.9. None of the sample ranges falls outside the control limits. Consequently, the process variability is in statistical control. If any of the sample ranges fall outside of the limits, or an unusual pattern appears (see Figure 3.9), we would search for the causes of the excessive variability, address them, and repeat step 1.

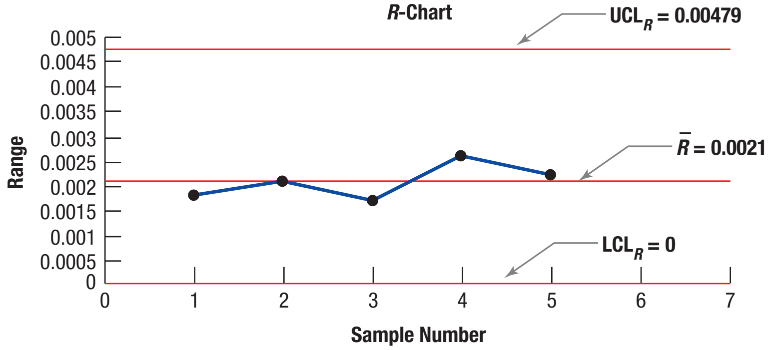


FIGURE 3.9
Range Chart from the *OM Explorer* $\bar{x}$- and *R-Chart* Solver, Showing that the Process Variability Is In Control

Step 5. Compute the mean for each sample. For example, the mean for sample 1 is

$$\frac{0.5014 + 0.5022 + 0.5009 + 0.5027}{4} = 0.5018 \text{ inch}$$

Similarly, the means of samples 2, 3, 4, and 5 are 0.5027, 0.5026, 0.5020, and 0.5045 inch, respectively. As shown in the table, $\bar{\bar{x}} = 0.5027$.

Step 6. Now, construct the $\bar{x}$-chart for the process average. The average screw diameter is 0.5027 inch, and the average range is 0.0021 inch, so use $\bar{\bar{x}} = 0.5027$, $\overline{R} = 0.0021$, and A_2 from Table 3.1 for a sample size of 4 to construct the control limits:

$$\text{UCL}_{\bar{x}} = \bar{\bar{x}} + A_2\overline{R} = 0.5027 + 0.729(0.0021) = 0.5042 \text{ inch}$$

$$\text{LCL}_{\bar{x}} = \bar{\bar{x}} - A_2\overline{R} = 0.5027 - 0.729(0.0021) = 0.5012 \text{ inch}$$

Step 7. Plot the sample means on the control chart, as shown in Figure 3.10.

The mean of sample 5 falls above the UCL, indicating that the process average is out of statistical control and that assignable causes must be explored, perhaps using a cause-and-effect diagram.

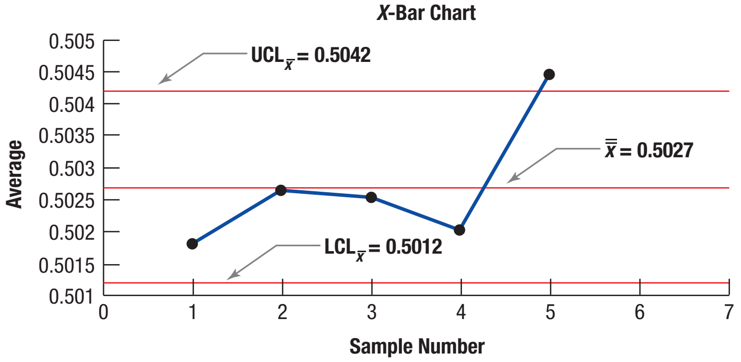


FIGURE 3.10
The $\bar{x}$-Chart from the *OM Explorer* $\bar{x}$- and *R-Chart* Solver for the Metal Screw, Showing that Sample 3 Is Out of Control

DECISION POINT

A new employee operated the lathe machine that makes the screw on the day sample 5 was taken. To solve the problem, management initiated a training session for the employee. Subsequent samples showed that the process was back in statistical control.

If the standard deviation of the process distribution is known, another form of the $\bar{x}$-chart may be used:

$$UCL_{\bar{x}} = \bar{\bar{x}} + z\sigma_{\bar{x}} \text{ and } LCL_{\bar{x}} = \bar{\bar{x}} - z\sigma_{\bar{x}}$$

where

$\sigma_{\bar{x}} = \sigma / \sqrt{n}$ = standard deviation of sample means

σ = standard deviation of the process distribution

n = sample size

$\bar{\bar{x}}$ = central line of the chart, which can be either the average of past sample means or a target value set for the process

z = normal deviate (number of standard deviations from the average)

The analyst can use an R-chart to be sure that the process variability is in control before constructing the $\bar{x}$-chart. The advantage of using this form of the $\bar{x}$-chart is that the analyst can adjust the spread of the control limits by changing the value of z. This approach can be useful for balancing the effects of type I and type II errors.

EXAMPLE 3.2 Designing an $\bar{x}$-Chart Using the Process Standard Deviation

The Sunny Dale Bank monitors the time required to serve customers at the drive-through window because it is an important quality factor in competing with other banks in the city. After analyzing the data gathered in an extensive study of the window operation, bank management determined that the mean time to process a customer at the peak demand period is 5 minutes, with a standard deviation of 1.5 minutes. Management wants to monitor the mean time to process a customer by periodically using a sample size of six customers. Assume that the process variability is in statistical control. Design an $\bar{x}$-chart that has a type I error of 5 percent. That is, set the control limits so that there is a 2.5 percent chance a sample result will fall below the LCL and a 2.5 percent chance that a sample result will fall above the UCL. After several weeks of sampling, two successive samples came in at 3.70 and 3.68 minutes, respectively. Is the customer service process in statistical control?

SOLUTION

$$\bar{\bar{x}} = 5.0 \text{ minutes}$$

$$\sigma = 1.5 \text{ minutes}$$

$$n = 6 \text{ customers}$$

$$z = 1.96$$

The process variability is in statistical control, so we proceed directly to the $\bar{x}$-chart. The control limits are

$$UCL_{\bar{x}} = \bar{\bar{x}} + z\sigma / \sqrt{n} = 5.0 + 1.96(1.5) / \sqrt{6} = 6.20 \text{ minutes}$$

$$LCL_{\bar{x}} = \bar{\bar{x}} - z\sigma / \sqrt{n} = 5.0 - 1.96(1.5) / \sqrt{6} = 3.80 \text{ minutes}$$

The value for z can be obtained in the following way. The normal distribution table (see Appendix 1) gives the proportion of the total area under the normal curve from $-\infty$ to z. We want a type I error of 5 percent, or 2.5 percent of the curve above the UCL and 2.5 percent below the LCL. Consequently, we need to find the z value in the table that leaves only 2.5 percent in the upper portion of the normal curve (or 0.9750 in the table). The value is 1.96. The two new samples are below the LCL of the chart, implying that the average time to serve a customer has dropped. Assignable causes should be explored to see what caused the improvement.

DECISION POINT

Management studied the time period over which the samples were taken and found that the supervisor of the process was experimenting with some new procedures. Management decided to make the new procedures a permanent part of the customer service process. After all employees were trained in the new procedures, new samples were taken and the control chart reconstructed.

Control Charts for Attributes

Two charts commonly used for performance measures based on attributes measures are the p- and c-chart. The p-chart is used for controlling the proportion of defects generated by the process. The c-chart is used for controlling the number of defects when more than one defect can be present in a service or product.

***p*-Charts** The ***p*-chart** is a commonly used control chart for attributes. The performance characteristic is counted rather than measured, and the entire service or item can be declared good or defective. For example, in the banking industry, the attributes counted might be the number of nonendorsed deposits or the number of incorrect financial statements sent to customers. The method involves selecting a random sample, inspecting each item in it, and calculating the sample proportion defective, p, which is the number of defective units divided by the sample size.

p-chart

A chart used for controlling the proportion of defective services or products generated by the process.

Sampling for a p-chart involves a "yes or no" decision: The process output either is or is not defective. The underlying statistical distribution is based on the binomial distribution. However, for large sample sizes, the normal distribution provides a good approximation to it. The standard deviation of the distribution of proportion defectives, σ_p, is

$$\sigma_p = \sqrt{\bar{p}(1 - \bar{p})/n}$$

where

n = sample size
$\bar{p}$ = central line on the chart, which can be either the historical average population proportion defective or a target value

We can use σ_p to arrive at the upper and lower control limits for a p-chart:

$$\text{UCL}_p = \bar{p} + z\sigma_p \quad \text{and} \quad \text{LCL}_p = \bar{p} - z\sigma_p$$

where

z = normal deviate (number of standard deviations from the average)

The chart is used in the following way. Periodically, a random sample of size n is taken, and the number of defective services or products is counted. The number of defectives is divided by the sample size to get a sample proportion defective, p, which is plotted on the chart. When a sample proportion defective falls outside the control limits, the analyst assumes that the proportion defective generated by the process has changed and searches for the assignable cause. Observations falling below the LCL_p indicate that the process may actually have improved. The analyst may find no assignable cause because it is always possible that an out-of-control proportion occurred randomly. However, if the analyst discovers assignable causes, those sample data should not be used to calculate the control limits for the chart.

EXAMPLE 3.3 Using a *p*-Chart to Monitor a Process

The operations manager of the booking services department of Hometown Bank is concerned about the number of wrong customer account numbers recorded by Hometown personnel. Each week a random sample of 2,500 deposits is taken, and the number of incorrect account numbers is recorded. The results for the past 12 weeks are shown in the following table. Is the booking process out of statistical control? Use three-sigma control limits, which will provide a type I error of 0.26 percent.

David R. Frazier Photolibrary, Inc./Alamy

A customer making a bank deposit in Boise, Idaho, USA.

MyOMLab

Active Model 6.2 in MyOMLab provides additional insight on the p-chart and its uses for the booking services department.

MyOMLab

Tutor 6.2 in MyOMLab provides a new example to practice the use of the p-chart.

Sample Number	Wrong Account Numbers	Sample Number	Wrong Account Numbers
1	15	7	24
2	12	8	7
3	19	9	10
4	2	10	17
5	19	11	15
6	4	12	3
			Total 147

SOLUTION

Step 1. Using this sample data to calculate $\overline{p}$

$$\overline{p} = \frac{\text{Total defectives}}{\text{Total number of observations}} = \frac{147}{12(2{,}500)} = 0.0049$$

$$\sigma_p = \sqrt{\overline{p}(1 - \overline{p})/n} = \sqrt{0.0049(1 - 0.0049)/2{,}500} = 0.0014$$

$$\text{UCL}_p = \overline{p} + z\sigma_p = 0.0049 + 3(0.0014) = 0.0091$$

$$\text{LCL}_p = \overline{p} - z\sigma_p = 0.0049 - 3(0.0014) = 0.0007$$

Step 2. Calculate each sample proportion defective. For sample 1, the proportion of defectives is $15/2{,}500 = 0.0060$.

Step 3. Plot each sample proportion defective on the chart, as shown in Figure 3.11.

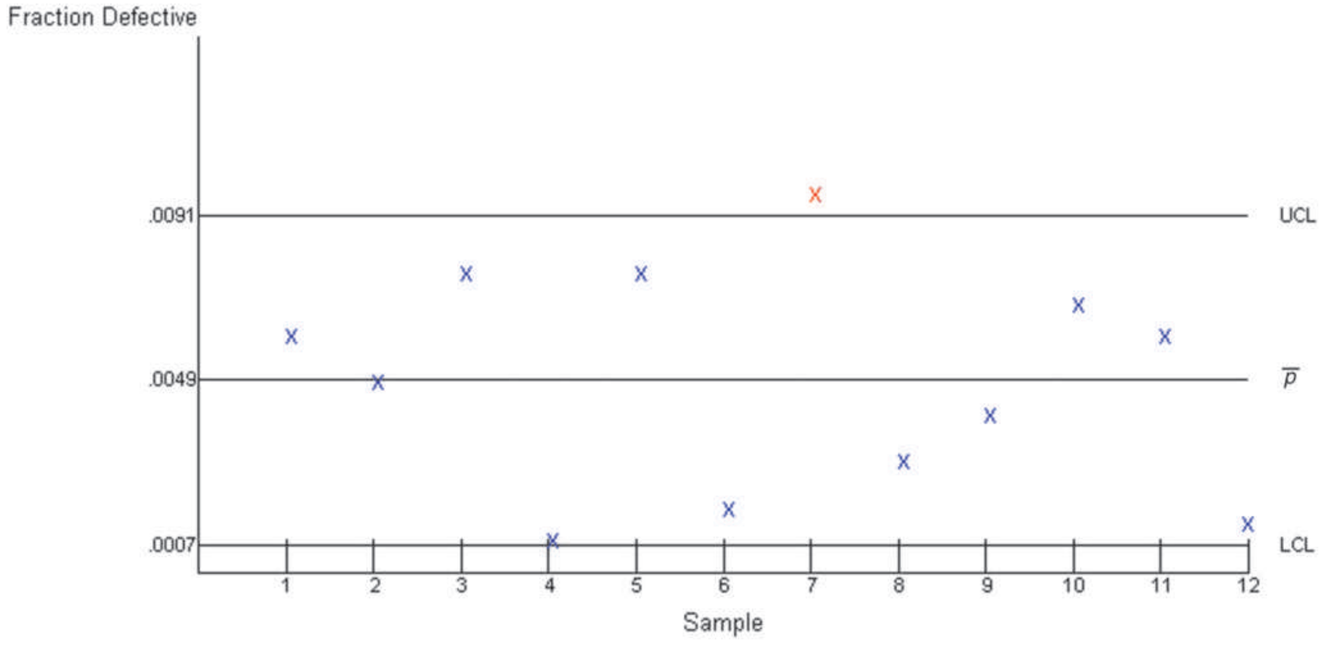


FIGURE 3.11
The *p*-Chart from POM for Windows for Wrong Account Numbers, Showing that Sample 7 Is Out of Control

Sample 7 exceeds the UCL; thus, the process is out of control and the reasons for the poor performance that week should be determined.

DECISION POINT

Management explored the circumstances when sample 7 was taken. The encoding machine used to print the account numbers on the checks was defective that week. The following week the machine was repaired; however, the recommended preventive maintenance on the machine was not performed for months prior to the failure. Management reviewed the performance of the maintenance department and instituted changes to the maintenance procedures for the encoding machine. After the problem was corrected, an analyst recalculated the control limits using the data without sample 7. Subsequent weeks were sampled, and the booking process was determined to be in statistical control. Consequently, the *p*-chart provides a tool to indicate when a process needs adjustment.

***c*-Charts** Sometimes services or products have more than one defect. For example, a roll of carpeting may have several defects, such as tufted or discolored fibers or stains from the production process. Other situations in which more than one defect may occur include accidents at a particular intersection, bubbles in a television picture face panel, and complaints from a patron at a hotel. When management is interested in reducing the number of defects per unit or service encounter, another type of control chart, the ***c*-chart**, is useful.

***c*-chart**
A chart used for controlling the number of defects when more than one defect can be present in a service or product.

The underlying sampling distribution for a *c*-chart is the Poisson distribution. The Poisson distribution is based on the assumption that defects occur over a continuous region on the surface of a product or a continuous time interval during the provision of a service. It further assumes that the probability of two or more defects at any one location on the surface or at any instant of time is negligible. The mean of the distribution is $\bar{c}$ and the standard deviation is $\sqrt{\bar{c}}$. A useful tactic is to use the normal approximation to the Poisson so that the central line of the chart is $\bar{c}$ and the control limits are

$$\text{UCL}_c = \bar{c} + z\sqrt{\bar{c}} \quad \text{and} \quad \text{LCL}_c = \bar{c} - z\sqrt{\bar{c}}$$

EXAMPLE 3.4 Using a *c*-Chart to Monitor Defects per Unit

The Woodland Paper Company produces paper for the newspaper industry. As a final step in the process, the paper passes through a machine that measures various product quality characteristics. When the paper production process is in control, it averages 20 defects per roll.

a. Set up a control chart for the number of defects per roll. For this example, use two-sigma control limits.

b. Five rolls had the following number of defects: 16, 21, 17, 22, and 24, respectively. The sixth roll, using pulp from a different supplier, had 5 defects. Is the paper production process in control?

A worker at a paper roll manufacturing facility.

H. Mark Weidman Photography/Alamy

MyOMLab
Tutor 3.3 in MyOMLab provides a new example to practice the use of the *c*-chart.

SOLUTION

a. The average number of defects per roll is 20. Therefore

$$\text{UCL}_c = \bar{c} + z\sqrt{\bar{c}} = 20 + 2(\sqrt{20}) = 28.94$$

$$\text{LCL}_c = \bar{c} - z\sqrt{\bar{c}} = 20 - 2(\sqrt{20}) = 11.06$$

The control chart is shown in Figure 3.12.

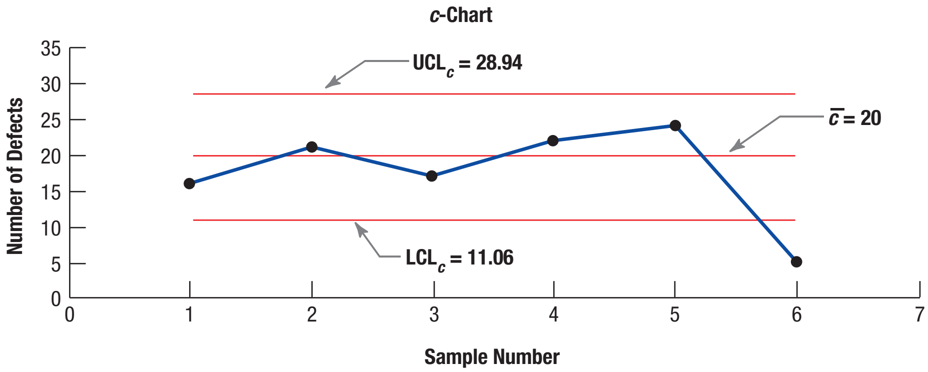


FIGURE 3.12
The *c*-Chart from the *OM Explorer c-Chart* Solver for Defects per Roll of Paper

b. Because the first five rolls had defects that fell within the control limits, the process is still in control. The sixth roll's five defects, however, is below than the LCL, and therefore, the process is technically "out of control." The control chart indicates that something good has happened.

DECISION POINT

The supplier for the first five samples has been used by Woodland Paper for many years. The supplier for the sixth sample is new to the company. Management decided to continue using the new supplier for a while, monitoring the number of defects to see whether it stays low. If the number remains below the LCL for 20 consecutive samples, management will make the switch permanent and recalculate the control chart parameters.

Process Capability

Statistical process control techniques help managers achieve and maintain a process distribution that does not change in terms of its mean and variance. The control limits on the control charts signal when the mean or variability of the process changes. However, a process that is in statistical control may not be producing services or products according to their design specifications, because the control limits are based on the mean and variability of the *sampling distribution*, not the design specifications. **Process capability** refers to the ability of the process to meet the design specifications for a service or product. Design specifications often are expressed as a **nominal value**, or target, and a **tolerance**, or allowance above or below the nominal value.

process capability
The ability of the process to meet the design specifications for a service or product.

nominal value
A target for design specifications.

tolerance
An allowance above or below the nominal value.

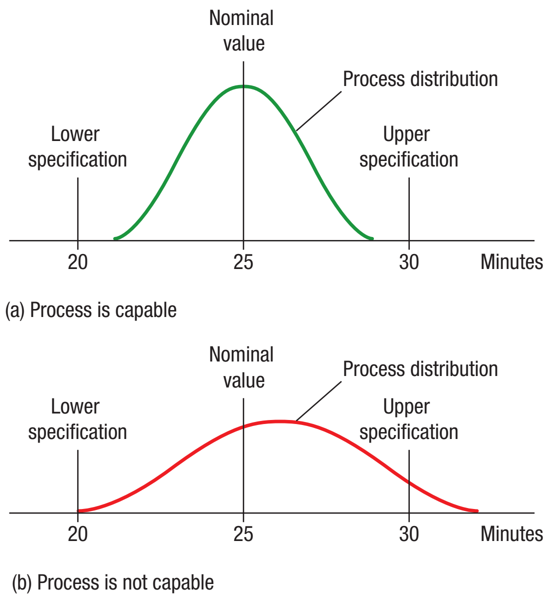
For example, the administrator of an intensive care unit lab might have a nominal value for the turnaround time of results to the attending physicians of 25 minutes and a tolerance of ± 5 minutes because of the need for speed under life-threatening conditions. The tolerance gives an *upper specification* of 30 minutes and a *lower specification* of 20 minutes. The lab process must be capable of providing the results of analyses within these specifications; otherwise, it will produce a certain proportion of "defects." The administrator is also interested in detecting occurrences of turnaround times of less than 20 minutes because something might be learned that can be built into the lab process in the future. For the present, the physicians are pleased with results that arrive within 20 to 30 minutes.

Defining Process Capability

Figure 3.13 shows the relationship between a process distribution and the upper and lower specifications for the lab process turnaround time under two conditions. In Figure 3.13(a), the process is capable because the extremes of the process distribution fall within the upper and lower specifications. In Figure 3.13(b), the process is not capable because the lab process produces too many reports with long turnaround times.

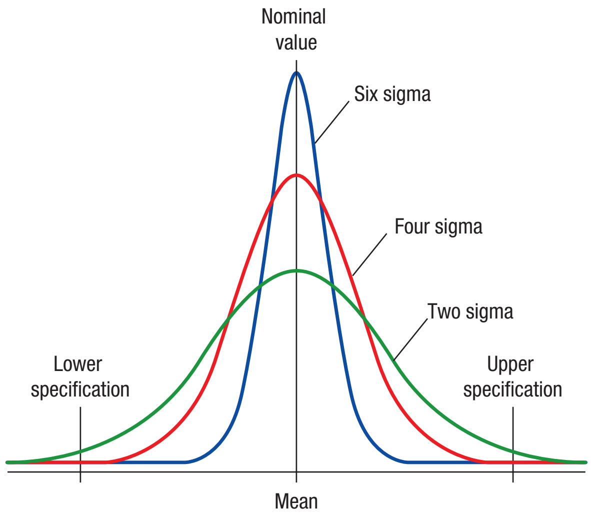
Figure 3.13 shows clearly why managers are so concerned with reducing process variability. The less variability—represented by lower standard deviations—the less frequently bad output is produced. Figure 3.14 shows what reducing variability implies for a process distribution that is a normal probability

FIGURE 3.13 ▶
The Relationship Between a Process Distribution and Upper and Lower Specifications



distribution. The firm with two-sigma performance (the specification limits equal the process distribution mean ± 2 standard deviations) produces 4.56 percent defects, or 45,600 defects per million. The firm with four-sigma performance produces only 0.0063 percent defects, or 63 defects per million. Finally, the firm with six-sigma performance produces only 0.0000002 percent defects, or 0.002 defects per million.[1]

How can a manager determine quantitatively whether a process is capable? Two measures commonly are used in practice to assess the capability of a process: the process capability index and the process capability ratio.



▲ **FIGURE 3.14**
Effects of Reducing Variability on Process Capability

Process Capability Index The **process capability index, C_{pk},** is defined as

$$C_{pk} = \text{Minimum of}\left[\frac{\bar{\bar{x}} - \text{Lower specification}}{3\sigma}, \frac{\text{Upper specification} - \bar{\bar{x}}}{3\sigma}\right]$$

where

$$\sigma = \text{standard deviation of the process distribution}$$

The process capability index measures how well the process is centered as well as whether the variability is acceptable. As a general rule, most values of any process distribution fall within ± 3 standard deviations of the mean. Consequently, ± 3 standard deviations are used as the benchmark. Because the process capability index is concerned with how well the process distribution is centered relative to the specifications, it checks to see if the process average is at least three standard deviations from the upper and lower specifications. We take the minimum of the two ratios because it gives the *worst-case* situation.

process capability index, C_{pk}
An index that measures the potential for a process to generate defective outputs relative to either upper or lower specifications.

The process capability index must be compared to a critical value to judge whether a process is capable. Firms striving to achieve three-sigma performance use a critical value for the ratio of 1.0. A firm targeting four-sigma performance will use 1.33 (or 4/3), a firm targeting five-sigma performance will use 1.67 (or 5/3), and a firm striving for six-sigma performance will use 2.00 (or 6/3). Processes producing services or products with less than three-sigma performance will have C_{pk} values less than 1.0.

If a process passes the process capability index test, we can declare the process is capable. Suppose a firm desires its processes to produce at the level of four-sigma performance. If C_{pk} is greater than or equal to the critical value of 1.33, we can say the process is capable. If C_{pk} is less than the critical value, either the process average is too close to one of the tolerance limits and is generating defective output, or the process variability is too large. To find out whether the variability is the culprit, we need another test.

Process Capability Ratio If a process fails the process capability *index* test, we need a quick test to see if the process variability is causing the problem. If a process is *capable*, it has a process distribution whose extreme values fall within the upper and lower specifications for a service or product. For example, if the process distribution is normal, 99.74 percent of the values fall within ± 3 standard deviations. In other words, the range of values of the quality measure generated by a process is approximately six standard deviations of the process distribution. Hence, if a process is capable at the three-sigma level, the difference between the upper and lower specification, called the *tolerance width*, must be greater than six standard deviations. The **process capability ratio, C_p,** is defined as

process capability ratio, C_p
The tolerance width divided by six standard deviations.

$$C_p = \frac{\text{Upper specification} - \text{Lower specification}}{6\sigma}$$

Suppose management wants four-sigma capability in their processes, and a process just failed the process capability index test at that level. A C_p value of 1.33, say, implies that the variability of the process is at the level of four-sigma quality and that the process is capable of consistently producing outputs within specifications, assuming that the process is centered. Because C_p passed the test, but C_{pk} did not, we can assume that the problem is that the process is not centered adequately.

[1]Our discussion assumes that the process distribution has no assignable causes. Six Sigma programs, however, define defect performance with the assumption that the process average has moved 1.5 standard deviations. In such a case, there would be 3.4 defects per million. See **http://www.isixsigma.com** for the rationale behind that assumption.

Using Continuous Improvement to Determine the Capability of a Process

To determine the capability of a process to produce outputs within the tolerances, use the following steps.

Step 1. Collect data on the process output, and calculate the mean and the standard deviation of the process output distribution.

Step 2. Use the data from the process distribution to compute process control charts, such as an $\bar{x}$- and an R-chart.

Step 3. Take a series of at least 20 consecutive random samples of size n from the process and plot the results on the control charts. If the sample statistics are within the control limits of the charts, the process is in statistical control. If the process is not in statistical control, look for assignable causes and eliminate them. Recalculate the mean and standard deviation of the process distribution and the control limits for the charts. Continue until the process is in statistical control.

Step 4. Calculate the process capability *index*. If the results are acceptable, the process is capable and document any changes made to the process; continue to monitor the output by using the control charts. If the results are unacceptable, calculate the process capability *ratio*. If the results are acceptable, the process variability is fine and management should focus on centering the process. If the results of the process capability ratio are unacceptable, management should focus on reducing the variability in the process until it passes the test. As changes are made, recalculate the mean and standard deviation of the process distribution and the control limits for the charts and return to step 3.

EXAMPLE 3.5 Assessing the Process Capability of the Intensive Care Unit Lab

Reuters/Corbis Wire/Corbis

A doctor examines a specimen through his microscope in a lab at St. Vincent's Hospital.

The intensive care unit lab process has an average turnaround time of 26.2 minutes and a standard deviation of 1.35 minutes. The nominal value for this service is 25 minutes with an upper specification limit of 30 minutes and a lower specification limit of 20 minutes. The administrator of the lab wants to have four-sigma performance for her lab. Is the lab process capable of this level of performance?

SOLUTION

The administrator began by taking a quick check to see if the process is capable by applying the process capability index:

$$\text{Lower specification calculation} = \frac{26.2 - 20.0}{3(1.35)} = 1.53$$

$$\text{Upper specification calculation} = \frac{30.0 - 26.2}{3(1.35)} = 0.94$$

$$C_{pk} = \text{Minimum of } [1.53, 0.94] = 0.94$$

Since the target value for four-sigma performance is 1.33, the process capability index told her that the process was not capable. However, she did not know whether the problem was the variability of the process, the centering of the process, or both. The options available to improve the process depended on what is wrong.

She next checked the process variability with the process capability ratio:

$$C_p = \frac{30.0 - 20.0}{6(1.35)} = 1.23$$

The process variability did not meet the four-sigma target of 1.33. Consequently, she initiated a study to see where variability was introduced into the process. Two activities, report preparation and specimen slide preparation, were identified as having inconsistent procedures. These procedures were modified to provide consistent performance. New data were collected and the average turnaround was now 26.1 minutes with

MyOMLab

Active Model 3.3 in MyOMLab provides additional insight on the process capability problem at the intensive care unit lab.

MyOMLab

Tutor 3.4 in MyOMLab provides a new example to practice the process capability measures.

a standard deviation of 1.20 minutes. She now had the process variability at the four-sigma level of performance, as indicated by the process capability ratio:

$$C_p = \frac{30.0 - 20.0}{6(1.20)} = 1.39$$

However, the process capability index indicated additional problems to resolve:

$$C_{pk} = \text{Minimum of}\left[\frac{(26.1 - 20.0)}{3(1.20)}, \frac{(30.0 - 26.1)}{3(1.20)}\right] = 1.08$$

DECISION POINT

The lab process was still not at the level of four-sigma performance on turnaround time. The lab administrator searched for the causes of the off-center turnaround time distribution. She discovered periodic backlogs at a key piece of testing equipment. Acquiring a second machine provided the capacity to reduce the turnaround times to four-sigma capability.

International Quality Documentation Standards and Awards

Once a company has gone through the effort of making its processes capable, it must document its level of quality so as to better market its services or products. This documentation of quality is especially important in international trade. However, if each country had its own set of standards, companies selling in international markets would have difficulty complying with quality documentation standards in each country where they did business. To overcome this problem, the International Organization for Standardization devised a family of standards called ISO 9000 for companies doing business in the European Union. Subsequently, ISO 14000 was devised for environmental management systems and ISO 26000 for guidance on social responsibility.

The ISO 9001:2008 Documentation Standards

ISO 9001:2008 is the latest update of the ISO 9000 standards governing documentation of a quality program. According to the International Organization for Standardization, the ISO 9001:2008 standards address *quality management* by specifying what the firm does to fulfill the customer's quality requirements and applicable regulatory requirements, while aiming to enhance customer satisfaction and achieve continual improvement of its performance in pursuit of these objectives. Companies become certified by proving to a qualified external examiner that they comply with all the requirements. Once certified, companies are listed in a directory so that potential customers can see which companies are certified and to what level. Compliance with ISO 9001:2008 standards says *nothing* about the actual quality of a product. Rather, it indicates to customers that companies can provide documentation to support whatever claims they make about quality. As of 2009, more than 1 million organizations worldwide have been certified in the ISO 9000 family of documentation standards.

ISO 9001:2008
A set of standards governing documentation of a quality program.

The ISO 140001:2004 Environmental Management System

The **ISO 140001:2004** standards require documentation of a firm's environmental program. According to the International Organization for Standardization, the ISO 140001:2004 family addresses *environmental management* by specifying what the firm does to minimize harmful effects on the environment caused by its activities, and to achieve continual improvement of its environmental performance. The documentation standards require participating companies to keep track of their raw materials use and their generation, treatment, and disposal of hazardous wastes. Although not specifying what each company is allowed to emit, the standards require companies to prepare a plan for ongoing improvement in their environmental performance. ISO 140001:2004 covers a number of areas, including the following:

ISO 140001:2004
Documentation standards that require participating companies to keep track of their raw materials use and their generation, treatment, and disposal of hazardous wastes.

- *Environmental Management System.* Requires a plan to improve performance in resource use and pollutant output.
- *Environmental Performance Evaluation.* Specifies guidelines for the certification of companies.
- *Environmental Labeling.* Defines terms such as *recyclable*, *energy efficient*, and *safe for the ozone layer*.
- *Life-Cycle Assessment.* Evaluates the lifetime environmental impact from the manufacture, use, and disposal of a product.

To maintain their certification, companies must be inspected by outside, private auditors on a regular basis. Apart from large US based companies like Ford, General Motors, IBM, Honda of America, and Xerox, approximately 10,000 firms worldwide have registered for ISO 140001:2004.

Benefits of ISO Certification

Completing the certification process can take as long as 18 months and involve many hours of management and employee time. The cost of certification can exceed $1 million for large companies. Despite the expense and commitment involved in ISO certification, it bestows significant external and internal benefits. The external benefits come from the potential sales advantage that companies in compliance have. Companies looking for a supplier will more likely select a company that has demonstrated compliance with ISO documentation standards, all other factors being equal. Consequently, more and more firms are seeking certification to gain a competitive advantage.

Internal benefits can be substantial. Registered companies report an average of 48 percent increased profitability and 76 percent improvement in marketing. The British Standards Institute, a leading third-party auditor, estimates that most ISO 9001-registered companies experience a 10 percent reduction in the cost of producing a product because of the quality improvements they make while striving to meet the documentation requirements. Certification in ISO 9001:2008 requires a company to analyze and document its procedures, which is necessary in any event for implementing continuous improvement, employee involvement, and similar programs. The guidelines and requirements of the ISO documentation standards provide companies with a jump-start in pursuing TQM programs.

Benefits of the Baldrige Performance Excellence Program

Regardless of where a company does business, it is clear that all organizations have to produce high-quality products and services if they are to be competitive. To emphasize that point, in August 1987 the U.S. Congress signed into law the Malcolm Baldrige National Quality Improvement Act, creating the Malcolm Baldrige National Quality Award, which is now entitled the **Baldrige Performance Excellence Program** (**www.quality.nist.gov**). Named for the late secretary of commerce, who was a strong proponent of enhancing quality as a means of reducing the trade deficit, the award promotes, recognizes, and publicizes quality strategies and achievements.

Baldrige Performance Excellence Program

A program named for the late secretary of commerce, Malcolm Baldrige, who was a strong proponent of enhancing quality as a means of reducing the trade deficit; organizations vie for an award that promotes, recognizes, and publicizes quality strategies and achievements.

The application and review process for the Baldrige award is rigorous. However, the act of preparing the application itself is often a major benefit to organizations because it helps firms define what *quality* means for them. According to the U.S. Commerce Department's National Institute of Standards and Technology (NIST), investing in quality principles and performance excellence pays off in increased productivity, satisfied employees and customers, and improved profitability, both for customers and investors. The seven major criteria for the award are the following:

1. *Leadership.* Describes how senior leaders' actions guide and sustain the organization and how they communicate with the workforce and encourage high performance.
2. *Strategic Planning.* Describes how the organization establishes its strategy to address its strategic challenges, leverage its strategic advantages, and summarizes the organization's key strategic objectives and their related goals.
3. *Customer Focus.* Describes how the organization determines its service or product offerings and the mechanisms to support the customers' use of them.
4. *Measurement, Analysis, and Knowledge Management.* Describes how the organization measures, analyzes, reviews, and improves its performance through the use of data and information at all levels of the organization.
5. *Workforce Focus.* Describes how the organization engages, compensates, and rewards its workers and how they are developed to achieve high performance.
6. *Operations Focus.* Describes how the organization designs its work systems and determines its key processes to deliver customer value, prepare for potential emergencies, and achieve organizational success and sustainability.
7. *Results.* Describe the organization's performance and improvement in five categories: products and processes, customer focus, workforce focus, leadership and governance, and financial and market.

Customer satisfaction underpins these seven criteria. Criterion 7, "Results," is given the most weight in selecting winners.

LEARNING GOALS IN REVIEW

Learning Goal	Guidelines for Review	MyOMLab Resources
1 Define the four major costs of quality, and their relationship to the role of ethics in determining the overall costs of delivering products and services.	See the section "Costs of Quality," pp. 116–118, and understand how deceptive business practices can affect a customer's experiences and why the costs of quality should be balanced with ethical considerations.	**Video:** Process Performance and Quality at Starwood Hotels & Resorts
2 Explain the basic principles of Total Quality Management (TQM) and Six Sigma.	See the section "Total Quality Management and Six Sigma," pp. 118–122. Focus on the five customer definitions of quality, and the key Figures 3.1 and 3.2. Be sure to understand Figure 3.3, which shows the goals of Six Sigma.	**Video:** Process Performance and Quality at Starwood Hotels & Resorts
3 Understand how acceptance sampling and process performance approaches interface in a supply chain.	See the section "Acceptance Sampling," pp. 122–123. Figure 3.4 shows how TQM or Six Sigma works in a supply chain through the tactic of acceptance sampling.	**POM for Windows:** Acceptance Sampling **Supplement G:** Acceptance Sampling Plans
4 Describe how to construct process control charts and use them to determine whether a process is out of statistical control.	See the section "Statistical Process Control," pp. 123–134. Understanding Figures 3.5 and 3.6 is key to understanding the methods to follow. The subsections on "Control Charts," "Control Charts for Variables," and "Control Charts for Attributes," pp. 126–134, show you how to determine if a process is in statistical control. Study Examples 3.1 to 3.4 as well as Solved Problems 1 to 3.	**Active Model Exercises:** 3.1: *x*-bar and *R*-Charts; 3.2: *p*-Charts **OM Explorer Solvers:** *R*- and *x*-bar Charts; *c*-Charts; *p*-Charts **OM Explorer Tutors:** 3.1: *x*-bar and *R*-Charts; 3.2: *p*-Charts; 3.3: c-Charts **POM for Windows:** *x*-bar Charts; *p*-Charts; *c*-Charts
5 Explain how to determine whether a process is capable of producing a service or product to specifications.	The major take-away in the chapter is found in the section "Process Capability," pp. 134–137. Be sure you understand Figures 3.13 and 3.14; study Example 3.5 and Solved Problem 4.	**Active Model Exercise:** 3.3: Process Capability **OM Explorer Solver:** Process Capability **OM Explorer Tutor:** 3.4: Process Capability **POM for Windows:** Process Capability
6 Describe International Quality Documentation Standards and the Baldridge Performance Excellence Program.	The section "International Quality Documentation Standards and Awards," pp. 137–138, reviews details of different ISO standards and the Baldridge Award Program.	

Key Equations

Statistical Process Control

1. Sample mean:

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$$

2. Standard deviation of a sample:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} \quad \text{or} \quad \sigma = \sqrt{\frac{\sum_{i=1}^{n} x_i^2 - \frac{\left(\sum x_i\right)^2}{n}}{n-1}}$$

3. Control limits for variable process control charts

a. *R*-chart, range of sample:

$$\text{Upper control limit} = \text{UCL}_R = D_4\bar{R}$$
$$\text{Lower control limit} = \text{LCL}_R = D_3\bar{R}$$

b. $\bar{x}$-chart, sample mean:

$$\text{Upper control limit} = \text{UCL}_{\bar{x}} = \bar{\bar{x}} + A_2\bar{R}$$
$$\text{Lower control limit} = \text{LCL}_{\bar{x}} = \bar{\bar{x}} - A_2\bar{R}$$

c. When the standard deviation of the process distribution, σ, is known:

$$\text{Upper control limit} = \text{UCL}_{\bar{x}} = \bar{\bar{x}} + z\sigma_{\bar{x}}$$
$$\text{Lower control limit} = \text{LCL}_{\bar{x}} = \bar{\bar{x}} - z\sigma_{\bar{x}}$$

where

$$\sigma_{\bar{x}} = \frac{\sigma}{\sqrt{n}}$$

4. Control limits for attribute process control charts

a. p-chart, proportion defective:

$$\text{Upper control limit} = \text{UCL}_p = \bar{p} + z\sigma_p$$
$$\text{Lower control limit} = \text{LCL}_p = \bar{p} - z\sigma_p$$

where

$$\sigma_p = \sqrt{\bar{p}(1 - \bar{p})/n}$$

b. c-chart, number of defects:

$$\text{Upper control limit} = \text{UCL}_c = \bar{c} + z\sqrt{\bar{c}}$$
$$\text{Lower control limit} = \text{LCL}_c = \bar{c} - z\sqrt{\bar{c}}$$

Process Capability

5. Process capability index:

$$C_{pk} = \text{Minimum of}\left[\frac{\bar{\bar{x}} - \text{Lower specification}}{3\sigma}, \frac{\text{Upper specification} - \bar{\bar{x}}}{3\sigma}\right]$$

6. Process capability ratio:

$$C_p = \frac{\text{Upper specification} - \text{Lower specification}}{6\sigma}$$

Key Terms

acceptable quality level (AQL) 123
acceptance sampling 123
appraisal costs 117
assignable causes of variation 125
attributes 124
Baldrige Performance Excellence Program 138
c-chart 133
common causes of variation 125
continuous improvement 121
control chart 126
defect 116
employee empowerment 120
ethical failure costs 117
external failure costs 117
internal failure costs 117
ISO 9001:2008 137
ISO 140001:2004 137
nominal value 134
p-chart 131
plan-do-study-act cycle 121
prevention costs 117
process capability 134
process capability index, C_{pk} 135
process capability ratio, C_p 135
quality 119
quality at the source 120
R-chart 127
sample size 124
sampling plan 124
Six Sigma 121
statistical process control (SPC) 123
teams 120
tolerance 134
total quality management (TQM) 118
type I error 127
type II error 127
variables 124
warranty 117
$\bar{x}$-chart 128

Solved Problem 1

The Watson Electric Company produces incandescent light bulbs. The following data on the number of lumens for 40-watt light bulbs were collected when the process was in control.

MyOMLab Video

	OBSERVATION			
Sample	**1**	**2**	**3**	**4**
1	604	612	588	600
2	597	601	607	603
3	581	570	585	592
4	620	605	595	588
5	590	614	608	604

a. Calculate control limits for an R-chart and an $\bar{x}$-chart.

b. Since these data were collected, some new employees were hired. A new sample obtained the following readings: 625, 592, 612, and 635. Is the process still in control?

SOLUTION

a. To calculate $\bar{x}$, compute the mean for each sample. To calculate R, subtract the lowest value in the sample from the highest value in the sample. For example, for sample 1,

$$\bar{x} = \frac{604 + 612 + 588 + 600}{4} = 601$$

$$R = 612 - 588 = 24$$

Sample	$\bar{x}$	R
1	601	24
2	602	10
3	582	22
4	602	32
5	604	24
Total	2,991	112
Average	$\bar{\bar{x}} = 598.2$	$\bar{R} = 22.4$

The R-chart control limits are

$$UCL_R = D_4\bar{R} = 2.282(22.4) = 51.12$$
$$LCL_R = D_3\bar{R} = 0(22.4) = 0$$

The $\bar{x}$-chart control limits are

$$UCL_{\bar{x}} = \bar{\bar{x}} + A_2\bar{R} = 598.2 + 0.729(22.4) = 614.53$$
$$LCL_{\bar{x}} = \bar{\bar{x}} - A_2\bar{R} = 598.2 - 0.729(22.4) = 581.87$$

b. First check to see whether the variability is still in control based on the new data. The range is 43 (or $635 - 592$), which is inside the UCL and LCL for the R-chart. Since the process variability is in control, we test for the process average using the current estimate for $\bar{R}$. The average is 616 (or $(625 + 592 + 612 + 635)/4$), which is above the UCL for the $\bar{x}$-chart. Since the process average is out of control, a search for assignable causes inducing excessive average lumens must be conducted.

Solved Problem 2

The data processing department of the Arizona Bank has five data entry clerks. Each working day their supervisor verifies the accuracy of a random sample of 250 records. A record containing one or more errors is considered defective and must be redone. The results of the last 30 samples are shown in the table. All were checked to make sure that none was out of control.

Sample	Number of Defective Records	Sample	Number of Defective Records	Sample	Number of Defective Records	Sample	Number of Defective Records
1	7	9	6	17	12	24	7
2	5	10	13	18	4	25	13
3	19	11	18	19	6	26	10
4	10	12	5	20	11	27	14
5	11	13	16	21	17	28	6
6	8	14	4	22	12	29	11
7	12	15	11	23	6	30	9
8	9	16	8				
						Total	300

a. Based on these historical data, set up a p-chart using $z = 3$.

b. Samples for the next 4 days showed the following:

Sample	Number of Defective Records
Tues	17
Wed	15
Thurs	22
Fri	21

What is the supervisor's assessment of the data-entry process likely to be?

SOLUTION

a. From the table, the supervisor knows that the total number of defective records is 300 out of a total sample of 7,500 [or 30(250)]. Therefore, the central line of the chart is

$$\bar{p} = \frac{300}{7{,}500} = 0.04$$

The control limits are

$$\text{UCL}_p = \bar{p} + z\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} = 0.04 + 3\sqrt{\frac{0.04(0.96)}{250}} = 0.077$$

$$\text{LCL}_p = \bar{p} - z\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} = 0.04 - 3\sqrt{\frac{0.04(0.96)}{250}} = 0.003$$

b. Samples for the next 4 days showed the following:

Sample	Number of Defective Records	Proportion
Tues	17	0.068
Wed	15	0.060
Thurs	22	0.088
Fri	21	0.084

Samples for Thursday and Friday are out of control. The supervisor should look for the problem and, upon identifying it, take corrective action.

Solved Problem 3

The Minnow County Highway Safety Department monitors accidents at the intersection of Routes 123 and 14. Accidents at the intersection have averaged three per month.

a. Which type of control chart should be used? Construct a control chart with three-sigma control limits.

b. Last month, seven accidents occurred at the intersection. Is this sufficient evidence to justify a claim that something has changed at the intersection?

SOLUTION

a. The safety department cannot determine the number of accidents that did *not* occur, so it has no way to compute a proportion defective at the intersection. Therefore, the administrators must use a c-chart for which

$$\text{UCL}_c = \bar{c} + z\sqrt{\bar{c}} = 3 + 3\sqrt{3} = 8.20$$

$$\text{LCL}_c = \bar{c} - z\sqrt{\bar{c}} = 3 - 3\sqrt{3} = -2.196, \text{ adjusted to } 0$$

There cannot be a negative number of accidents, so the LCL in this case is adjusted to zero.

b. The number of accidents last month falls within the UCL and LCL of the chart. We conclude that no assignable causes are present and that the increase in accidents was due to chance.

Solved Problem 4

Pioneer Chicken advertises "lite" chicken with 30 percent fewer calories. (The pieces are 33 percent smaller.) The process average distribution for "lite" chicken breasts is 420 calories, with a standard deviation of the population of 25 calories. Pioneer randomly takes samples of six chicken breasts to measure calorie content.

a. Design an $\bar{x}$-chart using the process standard deviation. Use three-sigma limits.

b. The product design calls for the average chicken breast to contain 400 ± 100 calories. Calculate the process capability index (target $= 1.33$) and the process capability ratio. Interpret the results.

SOLUTION

a. For the process standard deviation of 25 calories, the standard deviation of the sample mean is

$$\sigma_{\bar{x}} = \frac{\sigma}{\sqrt{n}} = \frac{25}{\sqrt{6}} = 10.2 \text{ calories}$$

$$\text{UCL}_{\bar{x}} = \bar{\bar{x}} + z\sigma_{\bar{x}} = 420 + 3(10.2) = 450.6 \text{ calories}$$

$$\text{LCL}_{\bar{x}} = \bar{\bar{x}} - z\sigma_{\bar{x}} = 420 - 3(10.2) = 389.4 \text{ calories}$$

b. The process capability index is

$$C_{pk} = \text{Minimum of}\left[\frac{\bar{\bar{x}} - \text{Lower specification}}{3\sigma}, \frac{\text{Upper specification} - \bar{\bar{x}}}{3\sigma}\right]$$

$$= \text{Minimum of}\left[\frac{420 - 300}{3(25)} = 1.60, \frac{500 - 420}{3(25)} = 1.07\right] = 1.07$$

The process capability ratio is

$$C_p = \frac{\text{Upper specification} - \text{Lower specification}}{6\sigma} = \frac{500 \text{ calories} - 300 \text{ calories}}{6(25)} = 1.33$$

Because the process capability ratio is 1.33, the process should be able to produce the product reliably within specifications. However, the process capability index is 1.07, so the current process is not centered properly for four-sigma performance. The mean of the process distribution is too close to the upper specification.

Discussion Questions

1. Should a very pricey hand-crafted object of beauty, use automated equipment for manufacturing some of its component parts needed for assembling the object? Do you think it is a mistake to use automation in this way?
2. Healthy Food, a Singapore-based company operating in the sport-food sector, manufactures various supplements, energy bars and drinks, and fat burners. The company is now in the process of launching a new product—a chocolate energy bar for women, in addition to other products already commercialized by Healthy for the same customer type, and this should further consolidate the company's position in this segment. In this context, answer the following questions:
   a. What kind of quality control item could Healthy Food use to check if its new product is of a comparable standard with other such products?
   b. What can be the possible reasons of a non-standard result for the new product? Is this automatically an indication of poor quality or are there other explanations for such results? Provide reasons for your answer.
3. Explain how unethical business practices degrade the quality of the experience a customer has with a service or product. How is the International Organization for Standardization trying to encourage ethical business behavior?

Problems

The OM Explorer and POM for Windows software is available to all students using the 11th edition of this textbook. Go to **http://www.pearsonglobaleditions.com/Krajewski** to download these computer packages. If you purchased MyOMLab, you also have access to Active Models software and significant help in doing the following problems. Check with your instructor on how best to use these resources. In many cases, the instructor wants you to understand how to do the calculations by hand. At the least, the software provides a check on your calculations. When calculations are particularly complex and the goal is interpreting the results in making decisions, the software replaces entirely the manual calculations. The software also can be a valuable resource well after your course is completed.

Statistical Process Control

1. At Quickie Car Wash, the wash process is advertised to take less than 7 minutes. Consequently, management has set a target average of 440 seconds for the wash process. Suppose the average range for a sample of 7 cars is 9 seconds. Use Table 3.1 to establish control limits for sample means and ranges for the car wash process.
2. At Isogen Pharmaceuticals, the filling process for its asthma inhaler is set to dispense 170 milliliters (ml) of steroid solution per container. The average range for a sample of 6 containers is 5 ml. Use Table 3.1 to establish control limits for sample means and ranges for the filling process.
3. The Canine Gourmet Company produces delicious dog treats for canines with discriminating tastes. Management wants the box-filling line to be set so that the process average weight per packet is 45 grams. To make sure that the process is in control, an inspector at the end of the filling line periodically selects a random box of 10 packets and weighs each packet. When the process is in control, the range in the weight of each sample has averaged 6 grams.
   a. Design an R- and an $\bar{x}$-chart for this process.
   b. The results from the last 5 samples of 10 packets are

Sample	$\bar{x}$	R
1	44	9
2	40	2
3	46	5
4	39	8
5	48	3

   Is the process in control? Explain.

4. Aspen Plastics produces plastic bottles to customer order. The quality inspector randomly selects four bottles from the bottle machine and measures the outside diameter of the bottle neck, a critical quality dimension that determines whether the bottle cap will fit properly. The dimensions (inch) from the last six samples are

	BOTTLE			
Sample	1	2	3	4
1	0.594	0.622	0.598	0.590
2	0.587	0.611	0.597	0.613
3	0.571	0.580	0.595	0.602
4	0.610	0.615	0.585	0.578
5	0.580	0.624	0.618	0.614
6	0.585	0.593	0.607	0.569

   Assume that only these six samples are sufficient, and use the data to determine control limits for an R- and an $\bar{x}$-chart.

5. In an attempt to judge and monitor the quality of instruction, the administration of Mega-Byte Academy devised an examination to test students on the basic concepts that all should have learned. Each year, a random sample of 10 graduating students is selected for the test. The average score is used to track the quality of the educational process. Test results for the past 10 years are shown in Table 3.2.

   Use these data to estimate the center and standard deviation for this distribution. Then, calculate the two-sigma control limits for the process average. What comments would you make to the administration of the Mega-Byte Academy?

TABLE 3.2 | TEST SCORES ON EXIT EXAM

	STUDENT										
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Average**
1	63	57	92	87	70	61	75	58	63	71	69.7
2	90	77	59	88	48	83	63	94	72	70	74.4
3	67	81	93	55	71	71	86	98	60	90	77.2
4	62	67	78	61	89	93	71	59	93	84	75.7
5	85	88	77	69	58	90	97	72	64	60	76.0
6	60	57	79	83	64	94	86	64	92	74	75.3
7	94	85	56	77	89	72	71	61	92	97	79.4
8	97	86	83	88	65	87	76	84	81	71	81.8
9	94	90	76	88	65	93	86	87	94	63	83.6
10	88	91	71	89	97	79	93	87	69	85	84.9

6. The Money Pit Mortgage Company is interested in monitoring the performance of the mortgage process. Fifteen samples of five completed mortgage transactions each were taken during a period when the process was believed to be in control. The times to complete the transactions were measured. The means and ranges of the mortgage process transaction times, measured in days, are as follows:

Sample	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Mean	17	14	8	17	12	13	15	16	13	14	16	9	11	9	12
Range	6	11	4	8	9	14	12	15	10	10	11	6	9	11	13

Subsequently, samples of size 5 were taken from the process every week for the next 10 weeks. The times were measured and the following results obtained:

Sample	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
Mean	11	14	9	15	17	19	13	22	20	18
Range	7	11	6	4	12	14	11	10	8	6

a. Construct the control charts for the mean and the range, using the original 15 samples.

b. On the control charts developed in part (a), plot the values from samples 16 through 25 and comment on whether the process is in control.

c. In part (b), if you concluded that the process was out of control, would you attribute it to a drift in the mean, an increase in the variability, or both? Explain your answer.

7. Webster Chemical Company produces mastics and caulking for the construction industry. The product is blended in large mixers and then pumped into tubes and capped. Management is concerned about whether the filling process for tubes of caulking is in statistical control. The process should be centered on 8 ounces per tube. Several samples of eight tubes were taken, each tube was weighed, and the weights in Table 3.3 were obtained.

TABLE 3.3 | OUNCES OF CAULKING PER TUBE

	TUBE NUMBER							
Sample	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	7.98	8.34	8.02	7.94	8.44	7.68	7.81	8.11
2	8.33	8.22	8.08	8.51	8.41	8.28	8.09	8.16
3	7.89	7.77	7.91	8.04	8.00	7.89	7.93	8.09
4	8.24	8.18	7.83	8.05	7.90	8.16	7.97	8.07
5	7.87	8.13	7.92	7.99	8.10	7.81	8.14	7.88
6	8.13	8.14	8.11	8.13	8.14	8.12	8.13	8.14

a. Assume that only six samples are sufficient and develop the control charts for the mean and the range.

b. Plot the observations on the control chart and comment on your findings.

8. The Digital Guardian Company issues policies that protect clients from downtime costs due to computer system failures. It is very important to process the policies quickly because long cycle times not only put the client at risk, they could also lose business for Digital Guardian. Management is concerned that customer service is degrading because of long cycle times, measured in days. The following table contains the data from five samples, each sample consisting of eight random observations.

	OBSERVATION (DAYS)							
Sample	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	13	9	4	8	8	15	8	6
2	7	15	8	10	10	14	10	15
3	8	11	4	11	8	12	9	15
4	12	7	12	9	11	8	12	8
5	8	12	6	12	11	5	12	8

a. What is your estimate of the process average?

b. What is your estimate of the average range?

c. Construct an R- and an $\bar{x}$-chart for this process. Are assignable causes present?

9. The Precision Machining Company makes hand-held tools on an assembly line that produces one product every minute. On one of the products, the critical quality dimension is the diameter (measured in thousandths of an inch) of a hole bored in one of the assemblies. Management wants to detect any shift in the process average diameter from 0.015 inch. Management considers the variance in the process to be in control. Historically, the average range has been 0.002 inch, regardless of the process average. Design an $\bar{x}$-chart to control this process, with a center line at 0.015 inch and the control limits set at three sigmas from the center line.

   Management provided the results of 80 minutes of output from the production line, as shown in Table 3.4. During these 80 minutes, the process average changed once. All measurements are in thousandths of an inch.

   a. Set up an $\bar{x}$-chart with $n = 4$. The frequency should be sample four and then skip four. Thus, your first sample would be for minutes $1 - 4$, the second would be for minutes $9 - 12$, and so on. When would you stop the process to check for a change in the process average?

   b. Set up an $\bar{x}$-chart with $n = 8$. The frequency should be sample eight and then skip four. When would you stop the process now? What can you say about the desirability of large samples on a frequent sampling interval?

10. Using the data from Problem 9, continue your analysis of sample size and frequency by trying the following plans.

   a. Using the $\bar{x}$-chart for $n = 4$, try the frequency sample four, then skip eight. When would you stop the process in this case?

   b. Using the $\bar{x}$-chart for $n = 8$, try the frequency sample eight, then skip eight. When would you consider the process to be out of control?

   c. Using your results from parts (a) and (b), determine what trade-offs you would consider in choosing between them.

TABLE 3.4 SAMPLE DATA FOR PRECISION MACHINING COMPANY

Minutes	Diameter (thousandths of an inch)											
1–12	15	16	18	14	16	17	15	14	14	13	16	17
13–24	15	16	17	16	14	14	13	14	15	16	15	17
25–36	14	13	15	17	18	15	16	15	14	15	16	17
37–48	18	16	15	16	16	14	17	18	19	15	16	15
49–60	12	17	16	14	15	17	14	16	15	17	18	14
61–72	15	16	17	18	13	15	14	14	16	15	17	18
73–80	16	16	17	18	16	15	14	17				

11. Garcia's Garage desires to create some colorful charts and graphs to illustrate how reliably its mechanics "get under the hood and fix the problem." The historic average for the proportion of customers that return for the same repair within the 30-day warranty period is 0.10. Each month, Garcia tracks 100 customers to see whether they return for warranty repairs. The results are plotted as a proportion to report progress toward the goal. If the control limits are to be set at two standard deviations on either side of the goal, determine the control limits for this chart. In March, 8 of the 100 customers in the sample group returned for warranty repairs. Is the repair process in control?

12. As a hospital administrator of a large hospital, you are concerned with the absenteeism among nurses' aides. The issue has been raised by registered nurses, who feel they often have to perform work normally done by their aides. To get the facts, absenteeism data were gathered for the last three weeks, which is considered a representative period for future conditions. After taking random samples of 64 personnel files each day, the following data were produced:

Day	Aides Absent	Day	Aides Absent
1	2	9	2
2	5	10	3
3	2	11	5
4	6	12	3
5	6	13	11
6	2	14	4
7	6	15	7
8	5		

Because your assessment of absenteeism is likely to come under careful scrutiny, you would like a type I error of only 1 percent. You want to be sure to identify any instances of unusual absences. If some are present, you will have to explore them on behalf of the registered nurses.

a. Design a p-chart.

b. Based on your p-chart and the data from the last 3 weeks, what can you conclude about the absenteeism of nurses' aides?

13. The IRS is concerned with improving the accuracy of tax information given by its representatives over the telephone. Previous studies involved asking a set of 25 questions of a large number of IRS telephone representatives to determine the proportion of correct responses. Historically, the average proportion of correct responses has been 72 percent. Recently, IRS representatives have been receiving more training. On April 26, the set of 25 tax questions were again asked of 20 randomly selected IRS telephone representatives. The numbers of correct answers were 18, 16, 19, 21, 20, 16, 21, 16, 17, 10, 25, 18, 25, 16, 20, 15, 23, 19, 21, and 19.

a. What are the upper and lower control limits for the appropriate p-chart for the IRS? Use $z = 3$.

b. Is the tax information process in statistical control?

14. Management at Webster, in Problem 7, is now concerned as to whether caulking tubes are being properly capped. If a significant proportion of the tubes are not being sealed, Webster is placing its customers in a messy situation. Tubes are packaged in large boxes of 144. Several boxes are inspected, and the following numbers of leaking tubes are found:

Sample	Tubes	Sample	Tubes	Sample	Tubes
1	3	8	6	15	5
2	5	9	4	16	0
3	3	10	9	17	2
4	4	11	2	18	6
5	2	12	6	19	2
6	4	13	5	20	1
7	2	14	1	Total	72

Calculate p-chart three-sigma control limits to assess whether the capping process is in statistical control.

15. Janice Sanders, CEO of Pine Crest Medical Clinic, is concerned over the number of times patients must wait more than 30 minutes beyond their scheduled appointments. She asked her assistant to take random samples of 70 patients to see how many in each sample had to wait more than 30 minutes. Each instance is considered a defect in the clinic process. The table below contains the data for 15 samples.

Sample	Number of Defects
1	2
2	6
3	7
4	3
5	9
6	2
7	6
8	9
9	10
10	4
11	2
12	9
13	4
14	5
15	2

a. Assuming Janice Sanders is willing to use three-sigma control limits, construct a p-chart.

b. Based on your p-chart and the data in the table, what can you conclude about the waiting time of the patients?

16. Representatives of the Patriot Insurance Company take medical information over the telephone from prospective policy applicants prior to a visit to the applicant's place of residence by a registered nurse who takes vital sign measurements. When the telephone interview has incorrect or incomplete information, the entire process of approving the application is unnecessarily delayed and has the potential of causing loss of business. The following data were collected to see how many applications contain errors. Each sample has 200 randomly selected applications.

Sample	Defects	Sample	Defects
1	20	16	15
2	18	17	40
3	29	18	35
4	12	19	21
5	14	20	24
6	11	21	9
7	30	22	20
8	25	23	17
9	27	24	28
10	16	25	10
11	25	26	17
12	18	27	22
13	25	28	14
14	16	29	19
15	20	30	20

a. What are the upper and lower control limits of a p-chart for the number of defective applications? Use $z = 3$.

b. Is the process in statistical control?

17. The manager of the customer service department of Data Tech Credit Card Service Company is concerned about the number of defects produced by the billing process. Every day a random sample of 250 statements was inspected for errors regarding incorrect entries involving account numbers, transactions on the customer's account, interest charges, and penalty charges. Any statement with one or more of these errors was considered a defect. The study lasted 30 days and yielded the data in Table 3.5.

a. Construct a p-chart for the billing process.

b. Is there any nonrandom behavior in the billing process that would require management attention?

18. Red Baron Airlines serves hundreds of cities each day, but competition is increasing from smaller companies affiliated with major carriers. One of the key competitive priorities is on-time arrivals and departures. Red Baron defines *on time* as any arrival or departure that takes place within 15 minutes of the scheduled time. To stay on top of the market, management set the high standard of 98 percent on-time performance. The operations department was put in charge of monitoring the performance of the airline. Each week, a random sample of 300 flight arrivals and departures was checked for schedule performance. Table 3.6 contains the numbers of arrivals and departures over the last 30 weeks that did not meet Red Baron's definition of on-time service. Using three-sigma control limits based on 98 percent on time arrivals or departures, what can you tell the management about the quality of service? Can you identify any nonrandom behavior in the process? If so, what might cause the behavior?

TABLE 3.5 SAMPLE DATA FOR DATA TECH CREDIT CARD SERVICE

Samples	Number of Errors in Sample of 250									
1–10	3	8	5	11	7	1	12	9	0	8
11–20	3	5	7	9	11	3	2	9	13	4
21–30	12	10	6	2	1	7	10	5	8	4

TABLE 3.6 SAMPLE DATA FOR RED BARON AIRLINES

Samples	Number of Late Planes in Sample of 300 Arrivals and Departures									
1–10	3	8	5	11	7	2	12	9	1	8
11–20	3	5	7	9	12	5	4	9	13	4
21–30	12	10	6	2	1	8	4	5	8	2

19. A textile manufacturer wants to set up a control chart for irregularities (e.g., oil stains, shop soil, loose threads, and tears) per 100 square yards of carpet. The following data were collected from a sample of twenty 100-square-yard pieces of carpet:

Sample	1	2	3	4	5	6	7	8	9	10
Irregularities	11	8	9	12	4	16	5	8	17	10
Sample	11	12	13	14	15	16	17	18	19	20
Irregularities	11	5	7	12	13	8	19	11	9	10

a. Using these data, set up a c-chart with $z = 3$.

b. Suppose that the next five samples had 15, 18, 12, 22, and 21 irregularities. What do you conclude?

20. A travel agency is concerned with the accuracy and appearance of itineraries prepared for its clients. Defects can include errors in times, airlines, flight numbers, prices, car rental information, lodging, charge card numbers, and reservation numbers, as well as typographical errors. As the possible number of errors is nearly infinite, the agency measures the number of errors that do occur. The current process results in an average of three errors per itinerary.

a. What are the two-sigma control limits for these defects?

b. A client scheduled a trip to Dallas. Her itinerary contained six errors. Interpret this information.

21. Jim's Outfitters, Inc., makes custom fancy shirts for cowboys. The shirts could be flawed in various ways, including flaws in the weave or color of the fabric, loose buttons or decorations, wrong dimensions, and uneven stitches. Jim randomly examined 10 shirts, with the following results:

Shirt	Defects
1	8
2	0
3	7
4	12
5	5
6	10
7	2
8	4
9	6
10	6

a. Assuming that 10 observations are adequate for these purposes, determine the three-sigma control limits for defects per shirt.

b. Suppose that the next shirt has 13 flaws. What can you say about the process now?

22. The Big Black Bird Company produces fiberglass camper tops. The process for producing the tops must be controlled so as to keep the number of dimples low. When the process was in control, the following defects were found in 10 randomly selected camper tops over an extended period of time:

Top	Dimples
1	7
2	9
3	14
4	11
5	3
6	12
7	8
8	4
9	7
10	6

a. Assuming 10 observations are adequate for this purpose, determine the three-sigma control limits for dimples per camper top.

b. Suppose that the next camper top has 15 dimples. What can you say about the process now?

23. At Webster Chemical Company, lumps in the caulking compound could cause difficulties in dispensing a smooth bead from the tube. Even when the process is in control, an average of four lumps per tube of caulk will remain. Testing for the presence of lumps destroys the product, so an analyst takes random samples. The following results are obtained:

Tube No.	Lumps	Tube No.	Lumps	Tube No.	Lumps
1	6	5	6	9	5
2	5	6	4	10	0
3	0	7	1	11	9
4	4	8	6	12	2

Determine the *c*-chart two-sigma upper and lower control limits for this process. Is the process in statistical control?

Process Capability

24. The production manager at Sunny Soda, Inc., is interested in tracking the quality of the company's 12-ounce bottle filling line. The bottles must be filled within the tolerances set for this product because the dietary information on the label shows 12 ounces as the serving size. The design standard for the product calls for a fill level of 12.00 $\pm$ 0.10 ounces. The manager collected the following sample data (in fluid ounces per bottle) on the production process:

	OBSERVATION			
Sample	1	2	3	4
1	12.00	11.97	12.10	12.08
2	11.91	11.94	12.10	11.96
3	11.89	12.02	11.97	11.99
4	12.10	12.09	12.05	11.95
5	12.08	11.92	12.12	12.05
6	11.94	11.98	12.06	12.08
7	12.09	12.00	12.00	12.03
8	12.01	12.04	11.99	11.95
9	12.00	11.96	11.97	12.03
10	11.92	11.94	12.09	12.00
11	11.91	11.99	12.05	12.10
12	12.01	12.00	12.06	11.97
13	11.98	11.99	12.06	12.03
14	12.02	12.00	12.05	11.95
15	12.00	12.05	12.01	11.97

a. Are the process average and range in statistical control?

b. Is the process capable of meeting the design standard at four-sigma quality? Explain.

25. The Money Pit Mortgage Company made some changes to the process and undertook a process capability study. The following data were obtained for 15 samples of size 5. Based on the individual observations, management estimated the process standard deviation to be 4.22 (days) for use in the process capability analysis. The lower and upper specification limits (in days) for the mortgage process times were 2 and 19.

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Mean	8	9	5	13	10	10	14	13	10	11	15	6	12	11	6
Range	8	12	3	10	9	7	7	14	13	10	6	5	11	9	10

a. Calculate the process capability index and the process capability ratio values.

b. Suppose management would be happy with three-sigma performance. What conclusions is management likely to draw from the capability analysis? Can valid conclusions about the process be drawn from the analysis?

c. What remedial actions, if any, do you suggest that management take?

26. The Farley Manufacturing Company prides itself on the quality of its products. The company is engaged in competition for a very important project. A key element is a part that ultimately goes into precision testing equipment. The specifications are 8.000 $\pm$ 3.000 millimeters. Management is concerned about the capability of the process to produce that part. The following data (shown below) were randomly collected during test runs of the process:

	OBSERVATION (MILLIMETERS)							
Sample	1	2	3	4	5	6	7	8
1	9.100	8.900	8.800	9.200	8.100	6.900	9.300	9.100
2	7.600	8.000	9.000	10.100	7.900	9.000	8.000	8.800
3	8.200	9.100	8.200	8.700	9.000	7.000	8.800	10.800
4	8.200	8.300	7.900	7.500	8.900	7.800	10.100	7.700
5	10.000	8.100	8.900	9.000	9.300	9.000	8.700	10.000

Assume that the process is in statistical control. Is the process capable of producing the part at the three-sigma level? Explain.

27. A critical dimension of the service quality of a call center is the wait time of a caller to get to a sales representative. Periodically, random samples of three customer calls are measured for time. The results of the last four samples are in the following table:

Sample	Time (Sec)		
1	495	501	498
2	512	508	504
3	505	497	501
4	496	503	492

a. Assuming that management is willing to use three-sigma control limits, and using only the historical information contained in the four samples, show that the call center access time is in statistical control.

b. Suppose that the standard deviation of the process distribution is 5.77. If the specifications for the access time are 500 $\pm$ 18 sec., is the process capable? Why or why not? Assume three-sigma performance is desired.

28. An automatic lathe produces rollers for roller bearings, and statistical process control charts are used to monitor the process. The central line of the chart for the sample means is set at 8.50 and for the range at 0.31 mm. The process is in control, as established by samples of size 5. The upper and lower specifications for the diameter of the rollers are $(8.50 + 0.25)$ and $(8.50 - 0.25)$ mm, respectively.

a. Calculate the control limits for the mean and range charts.

b. If the standard deviation of the process distribution is estimated to be 0.13 mm, is the process capable of meeting specifications? Assume four-sigma performance is desired.

c. If the process is not capable, what percent of the output will fall outside the specification limits? (*Hint*: Use the normal distribution.)

29. Canine Gourmet Super Breath dog treats are sold in boxes labeled with a net weight of 12 ounces (340 grams) per box. Each box contains 8 individual 1.5-ounce packets. To reduce the chances of shorting the customer, product design specifications call for the packet-filling process average to be set at 43.5 grams so that the average net weight per box of 8 packets will be 348 grams. Tolerances are set for the box to weigh 348 $\pm$ 12 grams. The standard deviation for the *packet-filling* process is 1.01 grams. The target process capability ratio is 1.33. One day, the packet-filling process average weight drifts down to 43.0 grams. Is the packaging process capable? Is an adjustment needed?

30. Return to Problem 4 relating to Aspen Plastics producing plastic bottles to customer order. Suppose that the specification for the bottleneck diameter is 0.600 $\pm$ 0.050 and the population standard deviation is 0.013 inch.

a. What is the Process Capability Index?

b. What is the Process Capability Ratio?

c. If the firm is seeking four-sigma performance, is the process capable of producing the bottle?

31. Beaver Brothers, Inc., is conducting a study to assess the capability of its 150-gram bar soap production line. A critical quality measure is the weight of the soap bars after stamping. The lower and upper specification limits are 162 and 170 grams, respectively. As a part of an initial capability study, 25 samples of size 5 were collected by the quality assurance group and the observations in Table 3.7 were recorded.

After analyzing the data by using statistical control charts, the quality assurance group calculated the process capability ratio, C_p, and the process capability index, C_{pk}. It then decided to improve the stamping process, especially the feeder mechanism. After making all the changes that were deemed necessary, 18 additional samples were collected. The summary data for these samples are

$$\bar{\bar{x}} = 163 \text{ grams}$$

$$\bar{R} = 2.326 \text{ grams}$$

$$\sigma = 1 \text{ gram}$$

All sample observations were within the control chart limits. With the new data, the quality assurance group recalculated the process capability measures. It was pleased with the improved C_p but felt that the process should be centered at 166 grams to ensure that everything was in order. Its decision concluded the study.

a. Draw the control charts for the data obtained in the initial study and verify that the process was in statistical control.

b. What were the values obtained by the group for C_p and C_{pk} for the initial capability study? Comment on your findings and explain why further improvements were necessary.

c. What are the C_p and C_{pk} after the improvements? Comment on your findings, indicating why the group decided to change the centering of the process.

d. What are the C_p and C_{pk} if the process were centered at 166? Comment on your findings.

TABLE 3.7 SAMPLE DATA FOR BEAVER BROTHERS, INC.

Sample	OBS.1	OBS.2	OBS.3	OBS.4	OBS.5
1	167.0	159.6	161.6	164.0	165.3
2	156.2	159.5	161.7	164.0	165.3
3	167.0	162.9	162.9	164.0	165.4
4	167.0	159.6	163.7	164.1	165.4
5	156.3	160.0	162.9	164.1	165.5
6	164.0	164.2	163.0	164.2	163.9
7	161.3	163.0	164.2	157.0	160.6
8	163.1	164.2	156.9	160.1	163.1
9	164.3	157.0	161.2	163.2	164.4
10	156.9	161.0	163.2	164.3	157.3
11	161.0	163.3	164.4	157.6	160.6
12	163.3	164.5	158.4	160.1	163.3
13	158.2	161.3	163.5	164.6	158.7
14	161.5	163.5	164.7	158.6	162.5
15	163.6	164.8	158.0	162.4	163.6
16	164.5	158.5	160.3	163.4	164.6
17	164.9	157.9	162.3	163.7	165.1
18	155.0	162.2	163.7	164.8	159.6
19	162.1	163.9	165.1	159.3	162.0
20	165.2	159.1	161.6	163.9	165.2
21	164.9	165.1	159.9	162.0	163.7
22	167.6	165.6	165.6	156.7	165.7
23	167.7	165.8	165.9	156.9	165.9
24	166.0	166.0	165.6	165.6	165.5
25	163.7	163.7	165.6	165.6	166.2

Active Model Exercise

This Active Model appears in MyOMLab. It allows you to see the effects of sample size and z-values on control charts.

QUESTIONS

1. Has the booking process been in statistical control?
2. Suppose we use a 95 percent p-chart. How do the upper and lower control limits change? What are your conclusions about the booking process?
3. Suppose that the sample size is reduced to 2,000 instead of 2,500. How does this affect the chart?
4. What happens to the chart as we reduce the z-value?
5. What happens to the chart as we reduce the confidence level?

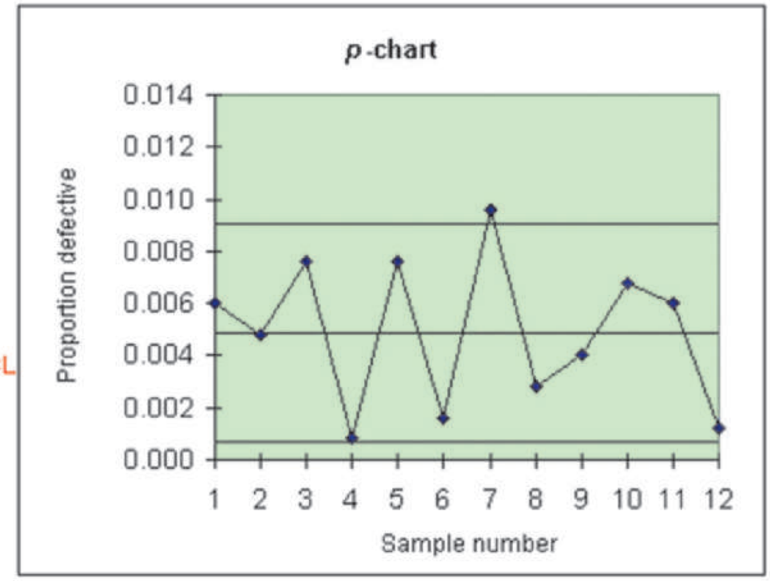
***p*-Chart**

Reset Data | Questions

Number of samples	12	
Sample size	2500	
z value	3.0000	
Confidence	99.73%	

	# Defects	Fraction Defective	
Sample 1	15	0.0060	
Sample 2	12	0.0048	
Sample 3	19	0.0076	
Sample 4	2	0.0008	
Sample 5	19	0.0076	
Sample 6	4	0.0016	
Sample 7	24	0.0096	Above UCL
Sample 8	7	0.0028	
Sample 9	10	0.0040	
Sample 10	17	0.0068	
Sample 11	15	0.0060	
Sample 12	3	0.0012	

Total sample size	30000	Upper Control Limit	0.0091
Total defects	147	Center Line	0.0049
Percentage defects	0.0049	Lower Control Limit	0.0007
Std dev of *p*-bar	0.0014		



p-Chart Using Data from Example 3.3

VIDEO CASE

Process Performance and Quality at Starwood Hotels & Resorts

Starwood Hotels & Resorts is no stranger to quality measurement. In the most recent year, Starwood properties around the globe held 51 of approximately 700 spots on Condé Nast's Gold List of the world's best places to stay. Its spa and golf programs have consistently been ranked among the best in the world.

At Starwood, processes and programs are driven by the work of its team of Six Sigma experts, called Black Belts. Developed by Motorola more than 20 years ago, Six Sigma is a comprehensive and flexible system for achieving, sustaining, and maximizing business success by driving out defects and variability in a process. Starwood uses the five-step DMAIC process: (1) define, (2) measure, (3) analyze, (4) improve, and (5) control.

Clearly, understanding customer needs is paramount. To this end, Starwood collects data from customers on its Guest Satisfaction Index survey, called the "Voice of the Customer." The survey covers every department guests may have encountered during their stay, from the front desk and hotel room, to restaurants and concierge. Past surveys indicated that how well problems were resolved during the guest stay was a key driver in high guest satisfaction scores. To increase its scores for problem resolution, the Sheraton brand of Starwood launched the Sheraton Service Promise program in the United States and Canada. The program was designed to give guests a single point of contact for reporting any problems. It was intended to focus associate (employee) attention on taking care of service issues during the guest's stay within 15 minutes of first receiving notice.

However, although scores did increase, they did not increase by enough. Consequently, Sheraton brought in its Six Sigma team to see what it could do. The team employed the basic Six Sigma model of define-measure-analyze-improve-control to guide its work. To define the problem, the Six Sigma team worked with data collected and analyzed by an independent survey organization, National Family Opinion. The study indicated that three key factors are needed in problem resolution: (1) speed, (2) empathy, and (3) efficiency. All three must be met in order for the guests to be satisfied and the Sheraton Service Promise fulfilled. Then, the team looked at the specific processes that affected performance: Telephone operators' handling of requests, procedures for determining who to call, engineering workloads, and

Pearson

Starwood has implemented Six Sigma quality programs to efficiently resolve guest problems at its properties around the globe.

so on. The work identified in each area was measured. For example, call logs were established to track speed, empathy of associate handling the call, and efficiency of the staff charged with fixing the problem. The data collected were analyzed to determine why guests' problems were not resolved within the 15-minute standard. Pareto charts and other techniques were used for the analysis.

The final step involved control and monitoring to be sure that the improved processes developed by the Six Sigma team became part of the property's culture, and that they were not abandoned after the team's work was finished. Tracking continues for 12 to 18 months, with monthly feedback to the manager or department head responsible for the improvement of the Sheraton Service Promise program. The improvement effort also receives visibility through the company's intranet so the rest of the organization sees the benefits—including service levels and financial performance—and can use the experience to improve their own operations.

QUESTIONS

1. Implementing Six Sigma programs takes considerable time and commitment from an organization. In terms of top-down commitment, measurement systems to track progress, tough goal setting, education, communication, and customer priorities, evaluate the degree to which Starwood successfully addressed each with the redesign of the Sheraton Service Promise program.
2. How might the new Sheraton Service Promise process help Starwood avoid the four costs of poor process performance and quality (prevention, appraisal, internal failure, and external failure)?
3. Starwood is the first major hotel brand to commit to a dedicated Six Sigma program for improving quality. Why might an organization be reluctant to follow this type of formalized methodology? What other approaches could Starwood or its competitors use?

EXPERIENTIAL LEARNING

Statistical Process Control with a Coin Catapult

Exercise A: Control Charts for Variables

Materials

1 ruler

1 pen or pencil

1 coin (a quarter will do nicely)

1 yardstick

An exercise worksheet

Access to a calculator

Tasks

Divide into teams of two to four. If four people are on a team,

one person holds the yardstick and observes the action,

one person adjusts the catapult and launches the coin,

one person observes the maximum height for each trial, and

one person records the results.

If teams of fewer than four are formed, provide a support for the yardstick and combine the other tasks as appropriate.

Practice

To catapult the coin, put a pen or pencil under the 6-inch mark of the ruler. Put the coin over the 11-inch mark. Press both ends of the ruler down as far as they will go. Let the end that holds the coin snap up, catapulting the coin into the air. The person holding the yardstick should place the stick so that it is adjacent to, but does not interfere with, the trajectory of the coin. To observe the maximum height reached by the coin, the observer should stand back with his or her eye at about the same level as the top of the coin's trajectory. Practice until each person is comfortable with his or her role. The person operating the catapult should be sure that the pen or pencil fulcrum has not moved between shots and that the launch is done as consistently as possible.

Step 1. *Gather data.* Take four samples of five observations (launches) each. Record the maximum height reached by the coin in the first data table on the worksheet. When you have finished, determine the mean and range for each sample, and compute the mean of the means $\bar{\bar{x}}$ and the mean of the ranges $\bar{R}$.

Step 2. *Develop an R-chart.* Using the data gathered and the appropriate D_3 and D_4 values, compute the upper and lower three-sigma control limits for the range. Enter these values and plot the range for each of the four samples on the range chart on the worksheet. Be sure to indicate an appropriate scale for range on the *y*-axis.

Step 3. *Develop an $\bar{x}$-chart.* Now, using the data gathered and the appropriate value for A_2, compute the upper and lower three-sigma control limits for the sample means. Enter these values and plot the mean for each of the four samples on the $\bar{x}$-chart on the worksheet. Again, indicate an appropriate scale for the *y*-axis.

Step 4. *Observe the process.* Once a control chart has been established for a process, it is used to monitor the process and to identify when it is not running normally. Collect two more samples of five trials each, as you did to collect the first set of data. Plot the range and the sample mean on the charts you constructed on the worksheet each time you collect a sample. What have you observed that affects the process? Does the chart indicate that the process is operating the way it did when you first collected data?

Step 5. *Observe a changed process.* Now change something (for instance, move the pencil out to the 8-inch mark). Collect data for samples 7 and 8. Plot the range and the sample mean on the charts you constructed on the worksheet as you complete each sample. Can you detect a change in the process from your control chart? If the process has changed, how sure are you that this change is real and not just due to the particular sample you chose?

Exercise B: Control Charts for Attributes

Materials

1 ruler

1 pen or pencil

1 coin (a quarter will do nicely)

1 paper or plastic cup (with a 4-inch mouth)

An exercise worksheet

Access to a calculator

Tasks

Divide into teams of two or three. If three people are on a team,

one person adjusts the catapult and launches the coin,

one person observes the results and fetches the coin, and

one person records the results.

If teams of two are formed, combine the tasks as appropriate.

Practice

The object is to flip a coin into a cup using a ruler. To catapult the coin, put a pen or pencil under the 6-inch mark of the ruler.

Put a coin over the 11-inch mark and let its weight hold that end of the ruler on the tabletop. Strike the raised end of the ruler with your hand to flip the coin into the air. Position a cup at the place where the coin lands so that on the next flip, the coin will land inside. You will have to practice several times until you find out how hard to hit the ruler and the best position for the cup. Be sure that the pen or pencil fulcrum has not moved between shots and that the launch is done as consistently as possible.

Step 1. *Gather data.* Try to catapult the coin into the cup 10 times for each sample. Record each trial in the data table on the worksheet as a hit (H) when the coin lands inside or a miss (M) when it does not. The proportion of misses will be the number of misses divided by the sample size, n, in this case 10. A miss is a "defect," so the proportion of misses is the proportion defective, p.

Step 2. *Develop a p-chart.* Compute the upper and lower three-sigma control limits for the average fraction defective. Plot these values and the mean for each of the four samples on the p-chart on the worksheet.

Step 3. *Observe the process.* Once a chart has been established for a process, it is used to monitor the process and to identify abnormal behavior. Exchange tasks so that someone else is catapulting the coin. After several practice launches, take four more samples of 10. Plot the proportion defective for this person's output. Is the process still in control? If it is not, how sure are you that it is out of control? Can you determine the control limits for a 95 percent confidence level? With these limits, was your revised process still in control?

Source: The basis for Exercise A was written by J. Christopher Sandvig, Western Washington University, as a variation of the "Catapulting Coins" exercise from *Games and Exercises for Operations Management* by Janelle Heinke and Larry Meile (Prentice Hall, 1995). Given these foundations, Larry Meile of Boston College wrote Exercise A. He also wrote Exercise B as a new extension. Reprinted by permission of Larry Meile.

Stan Honda/AFP/Getty Images/Newscom

Tesla's battery charging station emphasizes the close connection between the electric car and the batteries that serve as the main source of energy for this new generation automobile. Tesla's long-term growth strategies are therefore tied to also expanding its battery manufacturing capacity.

4

PLANNING CAPACITY

Tesla Motors

Driven by a need to reduce dependence on petroleum-based transportation, a new automobile manufacturing company, Tesla Motors, was formed by Silicon Valley engineers in 2003 with the idea of making fuel efficient electric cars that do not have an internal combustion engine and that run only on rechargeable batteries. Headquartered in Palo Alto, California, Tesla has over 600 employees and an expected revenue of over $3 billion in 2014. Its premium sedan Model S and cross-over utility vehicle Model X are sold through a network of 125 company-owned stores and service locations in North America, Europe, and Asia. Apart from a planned European Research and Development Center in the United Kingdom in 2015 or 2016, Tesla plans to open manufacturing plants in China and Europe once global sales pass 500,000 vehicles a year.

In order to meet the growing energy needs of its next-generation automobiles, Tesla announced plans in 2014 to build the world's largest battery factory at an expense of $4–5 billion. This gigantic Gigafactory would occupy 10 million square feet and employ about 6,500 workers once completed. It would manufacture the 18/650 cell, a cylindrical battery format that is 18 mm wide and 65 mm tall and favored by Tesla and some laptop manufacturers. About 8000 such cells, modified with Tesla's own proprietary chemistry, are needed to power the 85 kWh drive model S car. The completion of this plant in 2016–2017 is slated to coincide with the production of a third-generation Tesla car that would be a smaller version of model S but half priced at $35,000. Along with reduced raw material usage and a more efficient design, much of the price reduction of the new vehicle would come from a significant decrease in the cost of the battery pack made possible by the scale economies that arise with the construction of the Gigafactory. The supplier partner Panasonic, which expects to be the sole manufacturer in Tesla's Gigafactory, agrees that a reduction in battery pack cost of as much as 30 percent or higher may be possible. Having a car model that could potentially gain a large market share for electric vehicles at a lower price point could be a huge strategic advantage for Tesla Motors in the years to come. By expanding capacity beyond its immediate needs, Tesla could become a leading source for battery power if electric car sales continue to climb.

But the move by Tesla to expand capacity so dramatically for cylindrical cell batteries in such a large plant is not without its own perils. The plant's excess capacity may be underutilized in the first three years, as global production of Tesla cars starts gradually ramping up towards the 500,000 vehicles mark in 2020. In addition, other car manufacturers such as GM and Nissan use larger flat cell batteries that are not compatible with the cylindrical cells. So who would consume Tesla's excess battery capacity? While transition to a flat cell battery format may still be possible later on, productive use of such an expanded capacity may prove to be a challenging task for Tesla Motors in the near future.

Source: Mike Ramsey, "Will Tesla's $5 Billion Gigafactory Make a Battery Nobody Else Wants?" *Wall Street Journal* (April 14, 2014); **http://wardsauto.com/report-ceo-says-tesla-plans-european-plant** (July 16, 2014); **http://seekingalpha.com/article/2295695-teslas-gigafactory-and-why-competitors-should-worry** (July 1, 2014); **http://wardsauto.com/tesla-eyeing-third-li-ion-battery-factory-us** (June 3, 2014); **http://www.teslamotors.com/about** (July 18, 2014).

LEARNING GOALS *After reading this chapter, you should be able to:*

1. Define long-term capacity and its relationship with economies and diseconomies of scale.
2. Understand the main differences between the expansionist and wait-and-see capacity timing and sizing strategies.
3. Identify a systematic four-step approach for determining long-term capacity requirements and associated cash flows.
4. Describe how the common tools for capacity planning such as waiting-line models, simulation, and decision trees assist in capacity decisions.

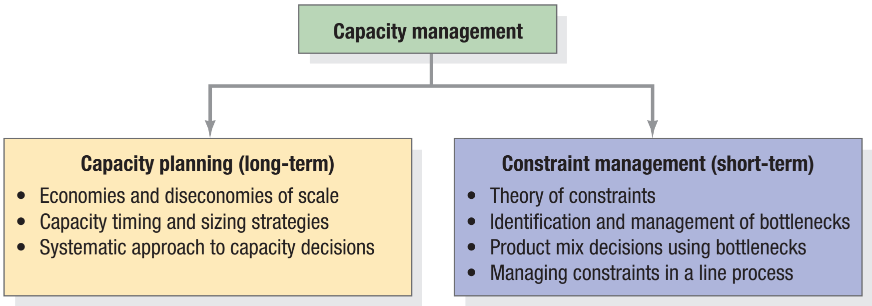
capacity

The maximum rate of output of a process or a system.

Capacity is the maximum rate of output of a process or a system. Managers are responsible for ensuring that the firm has the capacity to meet current and future demand. Otherwise, the organization will miss out on opportunities for growth and profits. Making adjustments to decrease capacity, or to increase it to facilitate the launch of an expanded product line as Tesla Motors did when planning a lower priced car model, is therefore an important part of the job. Acquisition of new capacity requires extensive planning and often involves significant expenditure of resources and time. Bringing new capacity online can take several years, for instance, in the semiconductor industry or in the construction of new nuclear power plants.

Capacity decisions related to a process need to be made in light of the role the process plays within the organization and the supply chain as a whole, because changing the capacity of a process will have an impact on other processes within the firm and across the chain. As such, capacity decisions have implications for different functional areas throughout the organization. Accounting needs to provide the cost information needed to evaluate capacity expansion decisions. Finance performs the financial analysis of proposed capacity expansion investments and raises funds to support them. Marketing provides demand forecasts needed to identify capacity gaps. Management information systems design the electronic infrastructure that is needed to make data such as cost information, financial performance measures, demand forecasts, and work standards available to those needing it to analyze capacity options. Operations is involved in the selection of capacity strategies that can be implemented to effectively meet future demand. Purchasing facilitates acquisition of outside capacity from suppliers. Finally, human resources focuses on hiring and training employees needed to support internal capacity plans. So all departments in a firm get involved with and are affected by long-term capacity planning decisions.

Increasing or decreasing capacity by itself is not as important as ensuring that the entire supply chain, from order entry to delivery, is designed for effectiveness. Capacity decisions must be made in light of several long-term issues such as the firm's economies and diseconomies of scale, capacity cushions, timing and sizing strategies, and trade-offs between customer service and capacity utilization. Therefore this chapter focuses on how managers can best revise capacity levels and best determine when to add or reduce capacity for the long term. The type of capacity decisions differ for different time horizons. Both long-term as well as short-term issues associated with planning capacity and managing constraints are important and must be understood in conjunction with one another. While we deal here with the long-term decisions shown below in the capacity management framework, short-term decisions centered on making the most of existing capacity by managing constraints are more fully explored in Chapter 5, "Managing Process Constraints."



Using Operations to Create Value
PROCESS MANAGEMENT
Process Strategy and Analysis
Managing Quality
Planning Capacity
Managing Process Constraints
Designing Lean Systems
Managing Effective Projects
CUSTOMER DEMAND MANAGEMENT
Forecasting Demand
Managing Inventories
Planning and Scheduling Operations
Efficient Resource Planning
SUPPLY CHAIN MANAGEMENT
Designing Effective Supply Chains
Supply Chains and Logistics
Integrating the Supply Chain
Managing Supply Chain Sustainability

Planning Long-Term Capacity

Long-term capacity plans deal with investments in new facilities and equipment at the organizational level and require top management participation and approval because they are not easily reversed. These plans cover at least two years into the future, but construction lead times can sometimes be longer and result in longer planning time horizons.

As already seen in our opening vignette, long-term capacity planning is central to the success of an organization. Too much capacity can be as agonizing as too little. Often entire industries can fluctuate over time between too much and too little capacity, as evidenced in the airline and cruise ship industry over the past 20 years. When choosing a capacity strategy, managers must consider questions such as the following: How much of a cushion is needed to handle variable, or uncertain, demand? Should we expand capacity ahead of demand, as Tesla did with battery production, or wait until demand is more certain? Even before these questions can be answered, a manager needs to be able to measure a process's capacity. So a systematic approach is needed to answer these and similar questions and to develop a capacity strategy appropriate for each situation.

Measures of Capacity and Utilization

No single capacity measure is best for all situations. A retailer measures capacity as annual sales dollars generated per square foot, whereas an airline measures capacity as available seat-miles (ASMs) per month. A theater measures capacity as number of seats, while a job shop measures capacity as number of machine hours. In general, capacity can be expressed in one of two ways: in terms of output measures or input measures.

Output Measures of Capacity *Output measures* of capacity are best utilized when applied to individual processes within the firm or when the firm provides a relatively small number of standardized services and products. High-volume processes, such as those in a car manufacturing plant, are a good example. In this case, capacity would be measured in terms of the number of cars produced per day. However, many processes produce more than one service or product. As the amount of customization and variety in the product mix increases, output-based capacity measures become less useful. Then input measures of capacity become the usual choice for measuring capacity.

Input Measures of Capacity *Input measures* are generally used for low-volume, flexible processes, such as those associated with a custom furniture maker. In this case, the furniture maker might measure capacity in terms of inputs such as number of workstations or number of workers. The problem with input measures is that demand is invariably expressed as an output rate. If the furniture maker wants to keep up with demand, he or she must convert the business's annual demand for furniture into labor hours and number of employees required to fulfill those hours. We will explain precisely how this input–output conversion is done later in the chapter.

utilization

The degree to which equipment, space, or the workforce is currently being used, and is measured as the ratio of average output rate to maximum capacity (expressed as a percent).

Utilization **Utilization** is the degree to which a resource such as equipment, space, or the workforce is currently being used and is measured as the ratio of average output rate to maximum capacity (expressed as a percent). The average output rate and the capacity must be measured in the same terms—that is, time, customers, units, or dollars. The utilization rate indicates the need for adding extra capacity or eliminating unneeded capacity.

$$\text{Utilization} = \frac{\text{Average output rate}}{\text{Maximum capacity}} \times 100\%$$

Here, we refer to maximum capacity as the greatest level of output that a process can reasonably sustain for a longer period, using realistic employee work schedules and the equipment currently in place. In some processes, this capacity level implies a one-shift operation; in others, it implies a three-shift operation. A process can be operated above its capacity level using marginal methods of production, such as overtime, extra shifts, temporarily reduced maintenance activities, overstaffing, and subcontracting. Although they help with temporary peaks, these options cannot be sustained for long. For instance, being able to handle 40 customers for a one-week peak is quite different from sustaining it for six months. Employees do not want to work excessive overtime for extended periods, so quality drops. In addition, the costs associated with overtime drive up the firm's costs. So operating processes close to (or even temporarily above) their maximum capacity can result in low customer satisfaction, minimal profits, and even losing money despite high sales levels. Such was the case with U.S. aircraft manufacturers in the late 1980s, which culminated in Boeing acquiring McDonnell Douglas in 1997 to shore up skyrocketing costs and plummeting profits.

Economies of Scale

economies of scale

A concept that states that the average unit cost of a service or good can be reduced by increasing its output rate.

Deciding on the best level of capacity involves consideration for the efficiency of the operations. A concept known as **economies of scale** states that the average unit cost of a service or good can be reduced by increasing its output rate. Four principal reasons explain why economies of scale can drive costs down when output increases: (1) Fixed costs are spread over more units; (2) construction costs are reduced; (3) costs of purchased materials are cut; and (4) process advantages are found.

Spreading Fixed Costs In the short term, certain costs do not vary with changes in the output rate. These fixed costs include heating costs, debt service, and managers' salaries. The depreciation of plant and equipment already owned is also a fixed cost in the accounting sense. When the average output rate—and, therefore, the facility's utilization rate—increases, the average unit cost drops because fixed costs are spread over more units.

Reducing Construction Costs Certain activities and expenses are required to build small and large facilities alike: building permits, architects' fees, and rental of building equipment. Doubling the size of the facility usually does not double construction costs.

Cutting Costs of Purchased Materials Higher volumes can reduce the costs of purchased materials and services. They give the purchaser a better bargaining position and the opportunity to take advantage of quantity discounts. Retailers such as Walmart reap significant economies of scale because their national and international stores buy and sell huge volumes of each item.

Finding Process Advantages High-volume production provides many opportunities for cost reduction. At a higher output rate, the process shifts toward a line process, with resources dedicated to individual products. Firms may be able to justify the expense of more efficient technology or more specialized equipment. The benefits from dedicating resources to individual services or products may include speeding up the learning effect, lowering inventory, improving process and job designs, and reducing the number of changeovers.

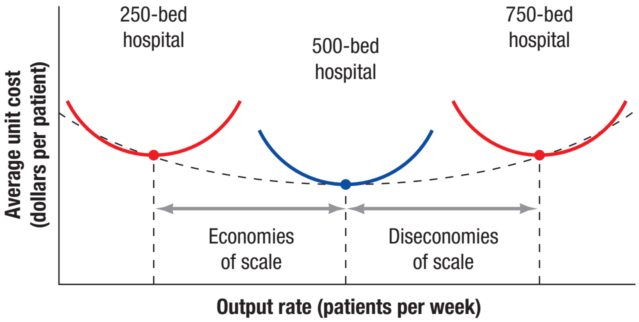
Diseconomies of Scale

diseconomies of scale

Occurs when the average cost per unit increases as the facility's size increases.

Bigger is not always better, however. At some point, a facility can become so large that **diseconomies of scale** set in; that is, the average cost per unit increases as the facility's size increases. The reason is that excessive size can bring complexity, loss of focus, and inefficiencies that raise the average unit cost of a service or product. Too many layers of employees and bureaucracy can cause management to lose touch with employees and customers. A less agile organization loses the flexibility needed to respond to changing demand. Many large companies become so involved in analysis and planning that they innovate less and avoid risks. The result is that small companies outperform corporate giants in numerous industries.

Figure 4.1 illustrates the transition from economies of scale to diseconomies of scale. The 500-bed hospital shows economies of scale because the average unit cost at its *best operating level*, represented by the blue dot, is less than that of the 250-bed hospital. However, assuming that sufficient demand exists, further expansion to a 750-bed hospital leads to higher average unit costs and diseconomies of scale. One reason the 500-bed hospital enjoys greater economies of scale than the 250-bed hospital is that the cost of building and equipping it is less than twice the cost for the smaller hospital. The 750-bed facility would enjoy similar savings. Its higher average unit costs can be explained only by diseconomies of scale, which outweigh the savings realized in construction costs.



▲ **FIGURE 4.1**
Economies and Diseconomies of Scale

Figure 4.1 does not mean that the optimal size for all hospitals is 500 beds. Optimal size depends on the number of patients per week to be served. On the one hand, a hospital serving a small community could have lower costs by choosing a 250-bed capacity rather than the 500-bed capacity. On the other hand, a large community might be served more efficiently by two 500-bed hospitals than by one 1,000-bed facility if diseconomies of scale exist at the bigger size.

Capacity Timing and Sizing Strategies

Operations managers must examine three dimensions of capacity strategy before making capacity decisions: (1) sizing capacity cushions, (2) timing and sizing expansion, and (3) linking process capacity and other operating decisions.

Sizing Capacity Cushions

Average utilization rates for any resource should not get too close to 100 percent over the long term, though it may occur for some processes from time to time in the short run. If the demand keeps increasing over time, then long-term capacity must be increased as well to provide some buffer against uncertainties. When average utilization rates approach 100 percent, it is usually a signal to increase capacity or decrease order acceptance to avoid declining productivity. The **capacity cushion** is the amount of reserve capacity a process uses to handle sudden increases in demand or temporary losses of production capacity; it measures the amount by which the average utilization (in terms of total capacity) falls below 100 percent. Specifically,

capacity cushion
The amount of reserve capacity a process uses to handle sudden increases in demand or temporary losses of production capacity; it measures the amount by which the average utilization (in terms of total capacity) falls below 100 percent.

$$\text{Capacity cushion, } C = 100\,(\%) - \text{Average Utilization rate}\,(\%)$$

The appropriate size of the cushion varies by industry. In the capital-intensive paper industry, where machines can cost hundreds of millions of dollars each, cushions well under 10 percent are preferred. The less capital-intensive hotel industry breaks even with a 60 to 70 percent utilization (40 to 30 percent cushion), and begins to suffer customer-service problems when the cushion drops to 20 percent. The more capital-intensive cruise ship industry prefers cushions as small as 5 percent. Large cushions are particularly vital for front-office processes where customers expect fast service times.

Businesses find large cushions appropriate when demand varies. In certain service industries (the grocery industry, for example), demand on some days of the week is predictably higher than on other days, and even hour-to-hour changes are typical. Long customer waiting times are not acceptable because customers grow impatient if they have to wait in a supermarket checkout line for more than a few minutes. Prompt customer service requires supermarkets to maintain a capacity cushion large enough to handle peak demand. Large cushions also are necessary when future demand is uncertain, particularly if resource flexibility is low. Simulation and waiting-line analysis (see Supplement B, "Waiting Line Models") can help managers better anticipate the relationship between capacity cushion and customer service.

Another type of demand uncertainty occurs with a changing product mix. Though total demand measured in monetary terms might remain stable, the load can shift unpredictably from one workstation to another as the product mix changes. Supply uncertainty tied to delivery of purchased materials also makes large capacity cushions helpful. Capacity often comes in large increments because a complete machine has to be purchased even if only a fraction of its available capacity is needed, which in turn creates a large cushion. Firms also need to build in excess capacity to allow for employee absenteeism, vacations, holidays, and any other delays. If a firm is experiencing high overtime costs and frequently needs to rely on subcontractors, it perhaps needs to increase its capacity cushions.

The argument in favor of small cushions is simple: Unused capacity costs money. For capital-intensive firms, minimizing the capacity cushion is vital. Studies indicate that businesses with high capital intensity achieve a low return on investment when the capacity cushion is high. This strong

Paul Vernon/Reuters

Accord ready to come off the line during a tour of the Honda automobile plant in Marysville, Ohio, October 11, 2012. The factory produces the Acura and Accord models and has an annual production of 440,000 vehicles. According to Green Car Reports, Honda will also move production of the 2014 Accord Hybrid from Sayama, Japan to Marysville, Ohio, and invest about $23 million more and hire 50 additional workers to accommodate this move.

correlation does not exist for labor-intensive firms, however. Their return on investment is about the same because the lower investment in equipment makes high utilization less critical. Small cushions have other advantages. By implementing a small cushion, a company can sometimes uncover inefficiencies that were difficult to detect when cushions were larger. These inefficiencies might include employee absenteeism or unreliable suppliers. Once managers and workers identify such problems, they often can find ways to correct them.

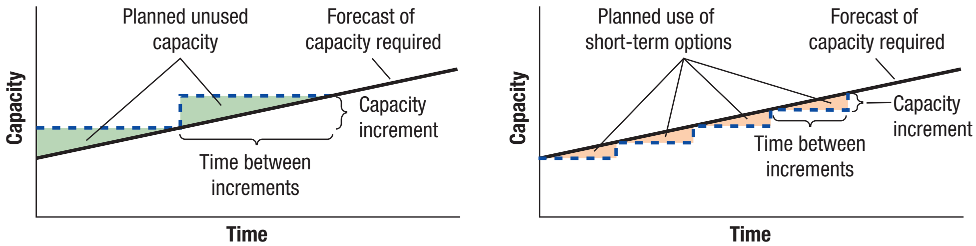
Timing and Sizing Expansion

The second issue of capacity strategy concerns when to adjust capacity levels and by how much. At times, capacity expansion can be done in response to changing market trends. General Motors decided to increase production capacity of the four-seat series hybrid car Chevrolet Volt from 30,000 units to 45,000 units in 2012 because of strong public interest. While we deal with this issue from the perspective of capacity expansion in greater detail here, it must be noted that firms may not always be looking to expand capacity but at times may be forced to retrench as evidenced by the situation in the airlines industry, where all major airlines have consolidated routes and reduced the total number of flights in the face of increasing oil costs. Some of this consolidation has been achieved through mergers like United Airlines and Continental to create the world's largest airline company, as well as the merger between Delta and Northwest Airlines.

Figure 4.2 illustrates two extreme strategies for expanding capacity: the *expansionist strategy*, which involves large, infrequent jumps in capacity, and the *wait-and-see strategy*, which involves smaller, more frequent jumps.

FIGURE 4.2 ▶
Two Capacity Strategies

MyOMLab Animation



(a) Expansionist strategy

(b) Wait-and-see strategy

Expansionist Strategy The timing and sizing of expansion are related; that is, if demand is increasing and the time between increments increases, the size of the increments must also increase. The expansionist strategy, which stays ahead of demand, minimizes the chance of sales lost to insufficient capacity.

Several factors favor the expansionist strategy. Expansion can result in economies of scale and a faster rate of learning, thus helping a firm reduce its costs and compete on price. This strategy might increase the firm's market share or act as a form of preemptive marketing. By making a large capacity expansion or announcing that one is imminent, the firm can preempt the expansion of other firms. These other firms must sacrifice some of their market share or risk burdening the industry with overcapacity. To be successful, however, the preempting firm must have the credibility to convince the competition that it will carry out its plans—and must signal its plans before the competition can act. Managerial Practice 4.1 illustrates the use of expansionist strategy by Sharp Corporation for its LCD panels and shows that using such a strategy can be both risky as well as potentially rewarding if correct judgments are made about its future use.

Wait-and-See Strategy The conservative wait-and-see strategy is to expand in smaller increments, such as by renovating existing facilities rather than building new ones. The wait-and-see strategy lags behind demand. To meet any shortfalls, it relies on short-term options, such as use of overtime,

MANAGERIAL PRACTICE 4.1 Expansionist Capacity Strategy by Sharp Corporation

Sharp Corporation, founded in 1912 in Japan, is a global manufacturer and distributor of consumer and information products such as LCD TVs and projectors, DVD recorders, mobile communication handsets, point-of-sale systems, home appliances such as refrigerators and microwave ovens, and electronic components such as flash memories, LCD panels, and optical sensors, among others. With over 50,000 employees, it has manufacturing, sales, and R&D presence in 25 different countries and regions of the world. For production of its large-size LCDs needed in television sets, Sharp increased the capacity of its Kameyama No. 2 plant in Japan from 15,000 LCD sheets per month in August 2006 to 30,000 LCD sheets per month during the second phase in January 2007. Capacity enhancements in the third phase (July 2007) were 60,000 LCD sheets per month. The world's largest LCD TV screen at that time, measuring 108 inch, was made at the Kameyama plant No. 2 from eighth-generation glass substrates.

Is such a rapid expansion of long-term capacity a good idea? Opinions vary. Even though Sharp had thrived in recent years due to its LCD business, the decision to expand was made because production capacity had reached its limit and Sharp was unable to meet its market demand. As a result, Sharp had been overtaken in global LCD television sales, and its share in the second quarter of 2006 was only 10.8 percent, fourth behind Sony, Samsung, and Philips Electronics. However, the competition did not stay idle even as Sharp quickly expanded its capacity for LCD sheets. A joint company of Sony and Samsung planned for opening a new plant in autumn of 2007 that would have the same capacity as Sharp's Kameyama plant. Critics feared that if all three major players continue to add capacity faster than the rate at which the market can grow, it would lead to a mature industry with too much capacity and too little profitability.

Meanwhile, Sharp's bet that large capacity investments in LCD sheets will help enhance its leadership position in the LCD industry well into the future seems to be paying off. With a newly launched IZGO display technology in March 2012 that was based on using eighth-generation glass substrates already being produced at Kameyama Plant No. 2, Sharp will become the first company in the world during 2013–2014 to achieve commercial production of high definition LCD panels for smartphones, tablets, and notebook PCs. Optimized production processes using the existing capacity for eighth-generation glass substrates, coupled with IGZO technology's ability to enable smaller thin-film transistors and increased light transmittance, will enable Sharp to meet vigorously growing demand for high definition LCD panels in market segments that are quite different from the television set segment for which the original Kameyama plant No. 2 was established in 2006 and then subsequently expanded.


STR/AFP/Getty Images

Sharp's Kameyama plant No. 2 in Japan

Source: William Trent, "LCD Producers Continue to Add Too Much Capacity as They Battle for Market Share," **http://seekingalpha.com/article/19038-lcd-producers-continue-to-add-too-much-capacity-as-they-battle-for-market-share** (October 2006); **http://www.sharp-world.com/corporate/info/ci/g_organization/index.html**, and **http://www.sharp-world.com/corporate/ir/event/policy_meeting/pdf/shar080108e_1.pdf** (May 31, 2011); **http://www.sharp-world.com/corporate/news/131017.html** (July 17, 2014), "Sharp to Begin Production of IZGO LCD Panels for Smartphones at Kameyama Plant No.2" (October 17, 2013).

temporary workers, subcontractors, stockouts, and the postponement of preventive maintenance on equipment. It reduces the risks of overexpansion based on overly optimistic demand forecasts, obsolete technology, or inaccurate assumptions regarding the competition.

However, this strategy has its own risks, such as being preempted by a competitor or being unable to respond if demand is unexpectedly high. Critics claim the wait-and-see strategy is a short-term strategy typical of some U.S. management styles. Managers on the fast track to corporate advancement tend to take fewer risks. They earn promotions by avoiding the big mistakes and maximizing short-term profits and return on investment. The wait-and-see strategy fits this short-term outlook but can erode market share over the long run.

Management may choose one of these two strategies or one of the many between these extremes. With strategies in the more moderate middle, firms can expand more frequently (on a smaller scale) than they can with the expansionist strategy without lagging behind demand as with the wait-and-see strategy. An intermediate strategy could be to *follow the leader*, expanding when others do. If others are right, so are you, and nobody gains a competitive advantage. If others make a mistake and over expand, so do you, but everyone shares in the agony of overcapacity. Such a situation was noted for the airlines industry, and may yet occur in the LCD industry due to large capacity expansions by Sharp Corporation, Sony, and Samsung as described in Managerial Practice 4.1.

Linking Capacity and Other Decisions

Capacity decisions should be closely linked to processes and supply chains throughout the organization. When managers make decisions about designing processes, determining degree of resource flexibility and inventory, and locating facilities, they must consider its impact on capacity cushions. Capacity cushions in the long run buffer the organization against uncertainty, as do resource flexibility, inventory, and longer customer lead times. If a change is made in any one decision area, the capacity cushion may also need to be changed to compensate. For example, capacity cushions for a process can be lowered if less emphasis is placed on fast deliveries (*competitive priorities*), yield losses (*quality*) drop, or if investment in capital-intensive equipment increases or worker flexibility increases (*process design*). Capacity cushions can also be lowered if the company is willing to smooth the output rate by raising prices when inventory is low and decreasing prices when it is high.

A Systematic Approach to Long-Term Capacity Decisions

Long-term decisions for capacity would typically include whether to add a new plant or warehouse or to reduce the number of existing ones, how many workstations a given department should have, or how many workers are needed to staff a given process. Some of these decisions can take years to become operational. Hence, a systematic approach is needed to plan for long-term capacity decisions.

Although each situation is somewhat different, a four-step procedure generally can help managers make sound capacity decisions. (In describing this procedure, we assume that management already performed the preliminary steps of determining the process's existing capacity and assessing whether its current capacity cushion is appropriate.)

1. Estimate future capacity requirements.
2. Identify gaps by comparing requirements with available capacity.
3. Develop alternative plans for reducing the gaps.
4. Evaluate each alternative, both qualitatively and quantitatively, and make a final choice.

Step 1: Estimate Capacity Requirements

capacity requirement

What a process's capacity should be for some future time period to meet the demand of customers (external or internal), given the firm's desired capacity cushion.

planning horizon

The set of consecutive time periods considered for planning purposes.

A process's **capacity requirement** is what its capacity should be for some future time period to meet the forecasted demand of the firm's customers (external or internal), given the firm's desired capacity cushion. Larger cushions than normal should be planned for those processes or workstations that could potentially become bottlenecks in the future.

Capacity requirements can be expressed in one of two ways: with an output measure or with an input measure. Either way, the foundation for the estimate is forecasts of demand, productivity, competition, and technological change. These forecasts normally need to be made for several time periods in a **planning horizon**, which is the set of consecutive time periods considered for planning purposes. Long-term capacity plans need to consider more of the future (perhaps, a whole decade) than do short-term plans. Unfortunately, the further ahead you look, the more chance you have of making an inaccurate forecast. See Chapter 8, "Forecasting Demand," for a complete discussion of forecast errors and their origins.

Using Output Measures The simplest way to express capacity requirements is as an output rate. As discussed earlier, output measures are appropriate for high-volume processes with little product variety or process divergence. Here, demand forecasts for future years are used as a basis for extrapolating capacity requirements into the future. If demand is expected to double in the next five years, then the capacity requirements also double. For example, if a process's current demand is 50 customers per day, then the demand in five years would be 100 customers per day. If the desired capacity cushion is 20 percent, management should plan for enough capacity to serve $[100/(1 - 0.2)] = 125$ customers in five years.

Using Input Measures Output measures may be insufficient in the following situations:

- Product variety and process divergence is high.
- The product or service mix is changing.
- Productivity rates are expected to change.
- Significant learning effects are expected.

In such cases, it is more appropriate to calculate capacity requirements using an input measure, such as the number of employees, machines, computers, or trucks. Using an input measure for the capacity requirement brings together demand forecasts, process time estimates, and the desired capacity cushion. When just one service or product is processed at an operation and the time period is a particular year, the capacity requirement, M, is

$$\text{Capacity requirement} = \frac{\text{Processing hours required for year's demand}}{\text{Hours available from a single capacity unit (such as an employee or machine) per year, after deducting desired cushion}}$$

$$M = \frac{Dp}{N[1 - (C/100)]}$$

where

$D =$ demand forecast for the year (number of customers served or units produced)

$p =$ processing time (in hours per customer served or unit produced)

$N =$ total number of hours per year during which the process operates

$C =$ desired capacity cushion (expressed as a percent)

$M =$ the number of input units required

M should be calculated for each year in the time horizon. The processing time, p, depends on the process and methods selected to do the work. The denominator is the total number of hours, N, available for the year from one unit of capacity (an employee or machine), multiplied by a proportion that accounts for the desired capacity cushion, C. The proportion is simply $1.0 - C/100$, where C is converted from a percent to a proportion by dividing by 100. For example, a 20 percent capacity cushion means that $1.0 - C/100 = 0.80$.

Setups may be involved if multiple products are being manufactured. **Setup time** is the time required to change a process or an operation from making one service or product to making another. The total setup time is found by dividing the number of units forecast per year, D, by the number of units made in each lot, Q, (number of units processed between setups), which gives the number of setups per year, and then multiplying by the time per setup, s. For example, if the annual demand is 1,200 units and the average lot size is 100, there are $1{,}200/100 = 12$ setups per year. Accounting for both processing and setup times for multiple services (products), we get

setup time
The time required to change a process or an operation from making one service or product to making another.

$$\text{Capacity requirement} = \frac{\text{Processing and setup hours required for year's demand, summed over all services or products}}{\text{Hours available from a single capacity unit per year, after deducting desired cushion}}$$

$$M = \frac{[Dp + (D/Q)s]_{\text{product 1}} + [Dp + (D/Q)s]_{\text{product 2}} + \cdots + [Dp + (D/Q)s]_{\text{product } n}}{N[1 - (C/100)]}$$

where

$Q =$ number of units in each lot

$s =$ setup time in hours per lot

What to do when M is not an integer depends on the situation. For example, it is impossible to buy a fractional machine. In this case, round up the fractional part, unless it is cost efficient to use short-term options, such as overtime or stockouts, to cover any shortfalls. If, instead, the capacity unit is the number of employees at a process, a value of 23.6 may be achieved using just 23 employees and a modest use of overtime (equivalent to having 60 percent of another full-time person). Here, the fractional value should be retained as useful information.

EXAMPLE 4.1 Estimating Capacity Requirements When Using Input Measures

A copy center in an office building prepares bound reports for two clients. The center makes multiple copies (the lot size) of each report. The processing time to run, collate, and bind each copy depends on, among other factors, the number of pages. The center operates 250 days per year, with one 8-hour shift. Management believes that a capacity cushion of 15 percent (beyond the allowance built into time standards) is best. It currently has three copy machines. Based on the following table of information, determine how many machines are needed at the copy center.

Item	Client X	Client Y
Annual demand forecast (copies)	2,000	6,000
Standard processing time (hour/copy)	0.5	0.7
Average lot size (copies per report)	20	30
Standard setup time (hours)	0.25	0.40

SOLUTION

$$M = \frac{[Dp + (D/Q)s]_{\text{product 1}} + [Dp + (D/Q)s]_{\text{product 2}} + \cdots + [Dp + (D/Q)s]_{\text{product } n}}{N[1 - (C/100)]}$$

$$= \frac{[2{,}000(0.5) + (2{,}000/20)(0.25)]_{\text{client X}} + [6{,}000(0.7) + (6{,}000/30)(0.40)]_{\text{client Y}}}{[(250 \text{ day/year})(1 \text{ shift/day})(8 \text{ hours/day})][1.0 - (15/100)]}$$

$$= \frac{5{,}305}{1{,}700} = \mathbf{3.12}$$

Rounding up to the next integer gives a requirement of **four** machines.

DECISION POINT

The copy center's capacity is being stretched and no longer has the desired 15 percent capacity cushion with the existing three machines. Not wanting customer service to suffer, management decided to use overtime as a short-term solution to handle past-due orders. If demand continues at the current level or grows, it will acquire a fourth machine.

Step 2: Identify Gaps

capacity gap

Positive or negative difference between projected demand and current capacity.

A **capacity gap** is any difference (positive or negative) between projected capacity requirements (M) and current capacity. Complications arise when multiple operations and several resource inputs are involved. Expanding the capacity of some operations may increase overall capacity. However, as we will learn later in Chapter 5, "Managing Process Constraints," if one operation is more constrained than others, total process capacity can be expanded only if the capacity of the constrained operation is expanded.

Step 3: Develop Alternatives

base case

The act of doing nothing and losing orders from any demand that exceeds current capacity, or incur costs because capacity is too large.

The next step is to develop alternative plans to cope with projected gaps. One alternative, called the **base case**, is to do nothing and simply lose orders from any demand that exceeds current capacity or incur costs because capacity is too large. Other alternatives if expected demand exceeds current capacity are various timing and sizing options for adding new capacity, including the expansionist and wait-and-see strategies illustrated in Figure 4.2. Additional possibilities include expanding at a different location and using short-term options, such as overtime, temporary workers, and subcontracting. Alternatives for reducing capacity include the closing of plants or warehouses, laying off employees, or reducing the days or hours of operation.

Step 4: Evaluate the Alternatives

In this final step, the manager evaluates each alternative, both qualitatively and quantitatively.

Qualitative Concerns Qualitatively, the manager looks at how each alternative fits the overall capacity strategy and other aspects of the business not covered by the financial analysis. Of particular concern might be uncertainties about demand, competitive reaction, technological change, and cost estimates. Some of these factors cannot be quantified and must be assessed on the basis of judgment and experience. Others can be quantified, and the manager can analyze each alternative by using different assumptions about the future. One set of assumptions could represent a worst case, in which demand is less, competition is greater, and construction costs are higher than expected. Another set of assumptions could represent the most optimistic view of the future. This type of "what-if" analysis allows the manager to get an idea of each alternative's implications before making a final choice.

Qualitative factors would tend to dominate when a business is trying to enter new markets or change the focus of its business strategy. For instance, Dell opened a data center in Shanghai in 2011 as part of its plans for a $1 billion investment in cloud computing (on-demand provision of computational resources for data and software through computer networks rather than local computers) and virtualization (creating a virtual rather than an actual version of an operating system or a storage device) and open other data centers around the world. Little hard data was available to guide the exact size and timing of the significant expansion of data center capacity that must be undertaken to support this diversification strategy, which will also include a deeper focus on sales training and expertise.


Yan Sheng/CNImaging/Newscom

Dell's Green Energy-saving and Environment-protecting Data Center will monitor the energy consumption index of 54 government offices in Beijing, China

Quantitative Concerns Quantitatively, the manager estimates the change in cash flows for each alternative over the forecast time horizon compared to the base case. **Cash flow** is the difference between the flows of funds into and out of an organization over a period of time, including revenues, costs, and changes in assets and liabilities. The manager is concerned here only with calculating the cash flows attributable to the project.

cash flow

The difference between the flows of funds into and out of an organization over a period of time, including revenues, costs, and changes in assets and liabilities.

EXAMPLE 4.2 Evaluating the Alternatives

Grandmother's Chicken Restaurant is experiencing a boom in business. The owner expects to serve 80,000 meals this year. Although the kitchen is operating at 100 percent capacity, the dining room can handle 105,000 diners per year. Forecasted demand for the next five years is 90,000 meals for next year, followed by a 10,000-meal increase in each of the succeeding years. One alternative is to expand both the kitchen and the dining room now, bringing their capacities up to 130,000 meals per year. The initial investment would be $200,000, made at the end of this year (year 0). The average meal is priced at $10, and the before-tax profit margin is 20 percent. The 20 percent figure was arrived at by determining that, for each $10 meal, $8 covers variable costs and the remaining $2 goes to pretax profit.

What are the pretax cash flows from this project for the next five years compared to those of the base case of doing nothing?

MyOMLab

Tutor 4.2 in MyOMLab provides a new example to practice projecting cash flows for capacity decisions.

SOLUTION

Recall that the base case of doing nothing results in losing all potential sales beyond 80,000 meals. With the new capacity, the cash flow would equal the extra meals served by having a 130,000-meal capacity, multiplied by a profit of $2 per meal. In year 0, the only cash flow is –$200,000 for the initial investment. In year 1, the 90,000-meal demand will be completely satisfied by the expanded capacity, so the incremental cash flow is (90,000 − 80,000) ($2) = $20,000. For subsequent years, the figures are as follows:

Year 2: Demand = 100,000; Cash flow = (100,000 − 80,000)$2 = $40,000

Year 3: Demand = 110,000; Cash flow = (110,000 − 80,000)$2 = $60,000

Year 4: Demand = 120,000; Cash flow = (120,000 − 80,000)$2 = $80,000

Year 5: Demand = 130,000; Cash flow = (130,000 − 80,000)$2 = $100,000

If the new capacity were smaller than the expected demand in any year, we would subtract the base case capacity from the new capacity (rather than the demand). The owner should account for the time value of money, applying such techniques as the net present value or internal rate of return methods (see MyOMLab Supplement F, "Financial Analysis"). For instance, the net present value (NPV) of this project at a discount rate of 10 percent is calculated here, and equals $13,051.76.

MyOMLab

$$\begin{aligned}\text{NPV} &= -200{,}000 + [(20{,}000/1.1)] + [40{,}000/(1.1)^2] + [60{,}000/(1.1)^3] + [80{,}000/(1.1)^4] + [100{,}000/(1.1)^5] \\ &= -\$200{,}000 + \$18{,}181.82 + \$33{,}057.85 + \$45{,}078.89 + \$54{,}641.07 + \$62{,}092.13 \\ &= \mathbf{\$13{,}051.76}\end{aligned}$$

DECISION POINT

Before deciding on this capacity alternative, the owner should also examine the qualitative concerns, such as future location of competitors. In addition, the homey atmosphere of the restaurant may be lost with expansion. Furthermore, other alternatives should be considered (see Solved Problem 2).

Tools for Capacity Planning

Capacity planning requires demand forecasts for an extended period of time. Unfortunately, forecast accuracy declines as the forecasting horizon lengthens. In addition, anticipating what competitors will do increases the uncertainty of demand forecasts. Demand during any period of time may not be evenly distributed; peaks and valleys of demand may (and often do) occur within the time period. These realities necessitate the use of capacity cushions. In this section, we introduce three tools that deal more formally with demand uncertainty and variability: (1) waiting-line models, (2) simulation, and (3) decision trees. Waiting-line models and simulation account for the random, independent behavior of many customers, in terms of both their time of arrival and their processing needs. Decision trees allow anticipation of events, such as competitors' actions, which requires a sequence of decisions regarding capacities.

Waiting-Line Models

Waiting-line models often are useful in capacity planning, such as selecting an appropriate capacity cushion for a high customer-contact process. Waiting lines tend to develop in front of a work center, such as an airport ticket counter, a machine center, or a central computer. The reason is that the arrival time between jobs or customers varies, and the processing time may vary from one customer to the next. Waiting-line models use probability distributions to provide estimates of average customer wait time, average length of waiting lines, and utilization of the work center. Managers can use this information to choose the most cost-effective capacity, balancing customer service and the cost of adding capacity.

Supplement B, "Waiting Line Models," follows this chapter and provides a fuller treatment of these models. It introduces formulas for estimating important characteristics of a waiting line, such as average customer waiting time and average facility utilization for different facility designs. For example, a facility might be designed to have one or multiple lines at each operation and to route customers through one or multiple operations. Given the estimating capability of these formulas and cost estimates for waiting and idle time, managers can select cost-effective designs and capacity levels that also provide the desired level of customer service.

Figure 4.3 shows output from POM for Windows for waiting lines. A professor meeting students during office hours has an arrival rate of three students per hour and a service rate of six students per hour. The output shows that the capacity cushion is 50 percent (1 − average server utilization of 0.50). This result is expected because the processing rate is double the arrival rate. What might not be expected is that a typical student spends 20 minutes either in line or talking with the professor, and the probability of having two or more students at the office is 0.25. These numbers might be surprisingly high, given such a large capacity cushion.

▼ **FIGURE 4.3**
POM for Windows Output for Waiting Lines during Office Hours

Waiting Lines Results

Example Solution

Parameter	Value	Parameter	Value	Minutes	Seconds
Single-Server Model		Average server utilization	.5		
Arrival rate(lambda)	3	Average number in the line(Lq)	.5		
Service rate(mu)	6	Average number in the system(L)	1		
Number of servers	1	Average time in the line(Wq)	.17	10	600
		Average time in the system(W)	.33	20	1200

Table of Probabilities

Example Solution

k	Prob (num in sys = k)	Prob (num in sys <= k)	Prob (num in sys >k)
0	.5	.5	.5
1	.25	.75	.25
2	.13	.88	.13
3	.06	.94	.06
4	.03	.97	.03
5	.02	.98	.02
6	.01	1	.01
7	.0	1	.0

Simulation

More complex waiting-line problems must be analyzed with simulation. It can identify the process's bottlenecks and appropriate capacity cushions, even for complex processes with random demand patterns and predictable surges in demand during a typical day. The SimQuick simulation package, provided in MyOMLab, allows you to build dynamic models and systems. Other simulation packages can be found with Extend, Simprocess, ProModel, and Witness.

MyOMLab

Decision Trees

A decision tree can be particularly valuable for evaluating different capacity expansion alternatives when demand is uncertain and sequential decisions are involved (see Supplement A, "Decision Making Models"). For example, the owner of Grandmother's Chicken Restaurant (see Example 4.2) may expand the restaurant now, only to discover in year 4 that demand growth is much higher than forecasted. In that case, she needs to decide whether to expand further. In terms of construction costs and downtime, expanding twice is likely to be much more expensive than building a larger facility from the outset. However, making a large expansion now, when demand growth is low, means poor facility utilization. Much depends on the demand.

Figure 4.4 shows a decision tree for this view of the problem, with new information provided. Demand growth can be either low or high, with probabilities of 0.40 and 0.60, respectively. The initial expansion in year 1 (square node 1) can either be small or large. The second decision node (square node 2), whether to expand at a later date, is reached only if the initial expansion is small and demand turns out to be high. If demand is high and if the initial expansion was small, a decision must be made about a second expansion in year 4. Payoffs for each branch of the tree are estimated. For example, if the initial expansion is large, the financial benefit is either $40,000 or $220,000, depending on whether demand is low or high. Weighting these payoffs by the probabilities yields an expected value of $148,000. This expected payoff is higher than the $109,000 payoff for the small initial expansion, so the better choice is to make a large expansion in year 1.

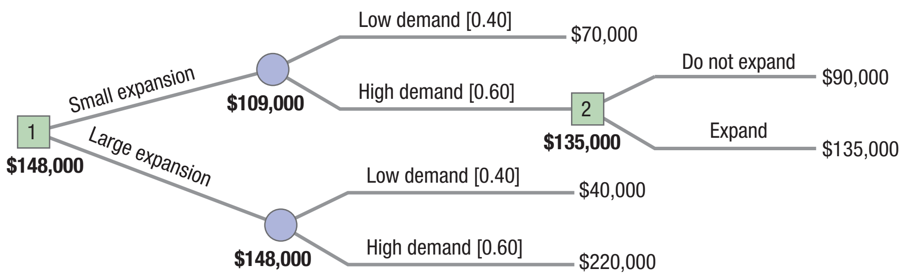


FIGURE 4.4 A Decision Tree for Capacity Expansion

LEARNING GOALS IN REVIEW

Learning Goal	Guidelines for Review	MyOMLab Resources
1 Define long-term capacity and its relationship with economies and diseconomies of scale.	Review the section "Measures of Capacity and Utilization," pp. 157–158, and understand why and how capacity is measured in high-volume processes is different from its measurement in low-volume, flexible processes. Also see the section on "Economies of Scale" and "Diseconomies of Scale," pp. 158–159. Figure 4.1 illustrates the relationship between average unit cost and output rate, and shows different output ranges over which economies and diseconomies of scale can occur.	**Video:** Gate Turnaround at Southwest Airlines
2 Understand the main differences between the expansionist and wait-and-see capacity timing and sizing strategies.	The section "Capacity Timing and Sizing Strategies," pp. 159–162, and Figure 4.2 differentiates between the expansionist and wait-and-see strategies. Understand the notion of capacity cushions, and how they link to other decisions in the firm.	
3 Identify a systematic four-step approach for determining long-term capacity requirements and associated cash flows.	The section "A Systematic Approach to Long-Term Capacity Decisions," pp. 162–165, shows you how capacity requirements can be estimated for both input-based as well as output-based measures. Focus on how different alternatives can be developed to fill the capacity gaps between requirements and current capacity.	**OM Explorer Solvers:** Capacity Requirements **OM Explorer Tutors:** 4.1: Capacity Requirements; 4.2: Projecting Cash Flows **MyOMLab Supplements:** F. Financial Analysis; H. Measuring Output Rates; I. Learning Curve Analysis **Additional Case:** Fitness Plus B

Learning Goal	Guidelines for Review	MyOMLab Resources
4 Describe how the common tools for capacity planning such as waiting-line models, simulation, and decision trees assist in capacity decisions.	The section "Tools for Capacity Planning," pp. 166–167, illustrates how several different methods can be used to arrive at capacity decisions.	

Key Equations

Planning Long-Term Capacity

1. Utilization, expressed as a percent:

$$\text{Utilization} = \frac{\text{Average output rate}}{\text{Maximum capacity}} \times 100\%$$

Capacity Timing and Sizing Strategies

2. Capacity cushion, C, expressed as a percent:

$$C = 100\% - \text{Average Utilization rate } (\%)$$

A Systematic Approach to Long-Term Capacity Decisions

3. Capacity requirement for one service or product:

$$M = \frac{Dp}{N[1 - (C/100)]}$$

4. Capacity requirement for multiple services or products:

$$M = \frac{[Dp + (D/Q)s]_{\text{product 1}} + [Dp + (D/Q)s]_{\text{product 2}} + \cdots + [Dp + (D/Q)s]_{\text{product } n}}{N[1 - (C/100)]}$$

Key Terms

base case 164
capacity 156
capacity cushion 159
capacity gap 164
capacity requirement 162
cash flow 165
diseconomies of scale 158
economies of scale 158
planning horizon 162
setup time 163
utilization 158

Solved Problem 1

MyOMLab Video

You have been asked to put together a capacity plan for a critical operation at the Surefoot Sandal Company. Your capacity measure is number of machines. Three products (men's, women's, and children's sandals) are manufactured. The time standards (processing and setup), lot sizes, and demand forecasts are given in the following table. The firm operates two 8-hour shifts, 5 days per week, 50 weeks per year. Experience shows that a capacity cushion of 5 percent is sufficient.

	TIME STANDARDS			
Product	**Processing (hr/pair)**	**Setup (hr/pair)**	**Lot Size (pairs/lot)**	**Demand Forecast (pairs/yr)**
Men's sandals	0.05	0.5	240	80,000
Women's sandals	0.10	2.2	180	60,000
Children's sandals	0.02	3.8	360	120,000

a. How many machines are needed?

b. If the operation currently has two machines, what is the capacity gap?

SOLUTION

a. The number of hours of operation per year, N, is $N =$ (2 shifts/day)(8 hours/shifts)(250 days/machine-year) $=$ 4,000 hours/machine-year

The number of machines required, M, is the sum of machine-hour requirements for all three products divided by the number of productive hours available for one machine:

$$M = \frac{[Dp + (D/Q)s]_{\text{men}} + [Dp + (D/Q)s]_{\text{women}} + [Dp + (D/Q)s]_{\text{children}}}{N[1 - (C/100)]}$$

$$= \frac{\begin{array}{c}[80{,}000(0.05) + (80{,}000/240)0.5] + [60{,}000(0.10) + (60{,}000/180)2.2] \\ + [120{,}000(0.02) + (120{,}000/360)3.8]\end{array}}{4{,}000[1 - (5/100)]}$$

$$= \frac{14{,}567 \text{ hours/year}}{3{,}800 \text{ hours/machine} - \text{year}} = \mathbf{3.83 \text{ or } 4} \text{ machines}$$

b. The capacity gap is 1.83 machines (3.83 $-$ 2). Two more machines should be purchased, unless management decides to use short-term options to fill the gap.

The *Capacity Requirements* Solver in OM Explorer confirms these calculations, as Figure 4.5 shows, using only the "Expected" scenario for the demand forecasts.

Shifts/Day	2
Hours/Shift	8
Days/Week	5
Weeks/Year	50
Cushion (as %)	5%
Current capacity	2

Components 3

More Components
Fewer Components

Components	Processing (hr/unit)	Setup (hr/lot)	Lot Size (units/lot)	Demand Forecasts Pessimistic	Expected	Optimistic
Men's sandals	0.05	0.5	240		80,000	
Women's sandals	0.10	2.2	180		60,000	
Children's sandals	0.02	3.8	360		120,000	

Productive hours from one capacity unit for a year 3,800

	Pessimistic Process	Setup	Expected Process	Setup	Optimistic Process	Setup
Men's sandals	0	0.0	4,000	166.7	0	0.0
Women's sandals	0	0.0	6,000	733.3	0	0.0
Children's sandals	0	0.0	2,400	1,266.7	0	0.0
	0	0.0	12,400	2,166.7	0	0.0
Total hours required		0.0		14,566.7		0.0

	Pessimistic	Expected	Optimistic
Total capacity requirements (M)	0.00	3.83	0.00
Rounded	0	4	0

Scenarios that can be met with current system/capacity: Pessimistic, Optimistic

If capacity increased by 0%
Expanded current capacity 3,800

	Pessimistic	Expected	Optimistic
Total capacity requirements (M)	0.00	3.83	0.00
Rounded	0	4	0

Scenarios that can be met with expanded current capacity: Pessimistic, Optimistic

FIGURE 4.5
Using the *Capacity Requirements* Solver for Solved Problem 1

Solved Problem 2

The base case for Grandmother's Chicken Restaurant (see Example 4.2) is to do nothing. The capacity of the kitchen in the base case is 80,000 meals per year. A capacity alternative for Grandmother's Chicken Restaurant is a two-stage expansion. This alternative expands the kitchen at the end of year 0, raising its capacity from 80,000 meals per year to that of the dining area (105,000 meals per year). If sales in year 1 and 2 live up to expectations, the capacities of both the kitchen and the dining room will be expanded at the *end* of year 3 to 130,000 meals per year. This upgraded capacity level should suffice up through year 5. The initial investment would be $80,000 at the end of year 0 and an additional investment of

\$170,000 at the end of year 3. The pretax profit is \$2 per meal. What are the pretax cash flows for this alternative through year 5, compared with the base case?

SOLUTION

Table 4.1 shows the cash inflows and outflows. The year 3 cash flow is unusual in two respects. First, the cash inflow from sales is \$50,000 rather than \$60,000. The increase in sales over the base is 25,000 meals (105,000 − 10,000) instead of 30,000 meals (110,000 − 80,000) because the restaurant's capacity falls somewhat short of demand. Second, a cash outflow of \$170,000 occurs at the end of year 3, when the second-stage expansion occurs. The net cash flow for year 3 is \$50,000 − \$170,000 = −\$120,000.

For comparison purposes, the NPV of this project at a discount rate of 10 percent is calculated as follows, and equals negative \$2,184.90.

$$
\begin{aligned}
\text{NPV} &= -80{,}000 + (20{,}000/1.1) + [40{,}000/(1.1)^2] - [120{,}000/(1.1)^3] + [80{,}000/(1.1)^4] + [100{,}000/(1.1)^5] \\
&= -\$80{,}000 + \$18{,}181.82 + \$33{,}057.85 - \$90{,}157.77 + \$54{,}641.07 + \$62{,}092.13 \\
&= \mathbf{-\$2{,}184.90}
\end{aligned}
$$

On a purely monetary basis, a single-stage expansion seems to be a better alternative than this two-stage expansion. However, other qualitative factors as mentioned earlier must be considered as well.

TABLE 4.1 | **CASH FLOWS FOR TWO-STAGE EXPANSION AT GRANDMOTHER'S CHICKEN RESTAURANT**

Year	Projected Demand (meals/yr)	Projected Capacity (meals/yr)	Calculation of Incremental Cash Flow Compared to Base Case (80,000 meals/yr)	Cash Inflow (outflow)
0	80,000	80,000	Increase kitchen capacity to 105,000 meals =	(\$80,000)
1	90,000	105,000	90,000 − 80,000 = (10,000 meals)(\$2/meal) =	\$20,000
2	100,000	105,000	100,000 − 80,000 = (20,000 meals)(\$2/meal) =	\$40,000
3	110,000	105,000	105,000 − 80,000 = (25,000 meals)(\$2/meal) =	\$50,000
			Increase total capacity to 130,000 meals =	(\$170,000)
				(\$120,000)
4	120,000	130,000	120,000 − 80,000 = (40,000 meals)(\$2/meal) =	\$80,000
5	130,000	130,000	130,000 − 80,000 = (50,000 meals)(\$2/meal) =	\$100,000

Discussion Questions

1. What are the economies of scale in college class size? As class size increases, what symptoms of diseconomies of scale appear? How are these symptoms related to customer contact?
2. Memotec Taiwan, a company that manufactures motherboards for laptops, has recently experienced a surge in its overseas orders. What type of considerations would you recommend this company offers for it to estimate its capacity requirements in the long run? Explain what the company has to take into account in order to decide whether to open a new plant or not.
3. Identify an industry in which expansionist strategy has generally been followed by most firms in the past. Under which conditions will it be better for a firm to follow the wait-and-see strategy rather than the expansionist strategy? Then identify a firm or an industry that has done so successfully.

Problems

The OM Explorer and POM for Windows software is available to all students using the 11th edition of this textbook. Go to **http://www.pearsonglobaleditions.com/krajewski** to download these computer packages. If you purchased MyOMLab, you also have access to Active Models software and significant help in doing the following problems. Check with your instructor on how best to use these resources. In many cases, the instructor wants you to understand how to do the calculations by hand. At the least, the software provides a check on your calculations. When calculations are particularly complex and the goal is interpreting the results in making decisions, the software replaces entirely the manual calculations.

Problems 20, 21, 22, 23, 24, and 25 require reading of Supplement A, "Decision Making Models." Problems 15, 16, 17, 24, and 25 require reading of MyOMLab Supplement F, "Financial Analysis."