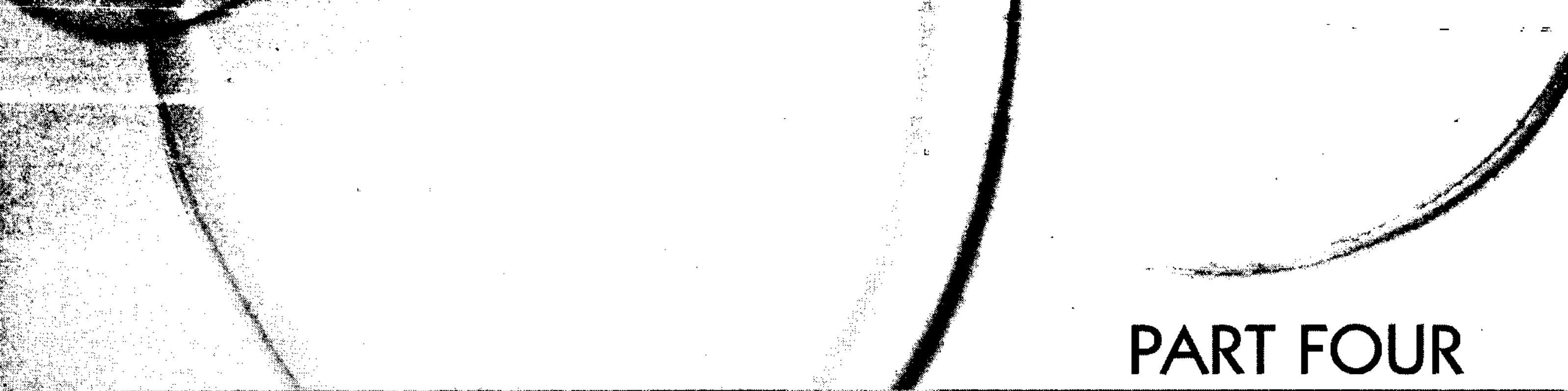

PART FOUR

Quality

The chapters in this part relate to quality.

Chapter 9 covers quality management. Among the topics discussed are the evolution of quality management, the dimensions of product and service quality, costs of quality, philosophies of several quality "gurus," quality awards and quality certification, total quality management and quality tools.

Chapter 10 covers quality control. The key topics include inspection, sampling, the construction and use of control charts, and the assessment of process capability.

The chapters in this section are:

CHAPTER 9

Management of Quality

LEARNING OBJECTIVES

After completing this chapter, you should be able to:

1. Define the term *quality*.
2. Explain why quality is important and the consequences of poor quality.
3. Identify the determinants of quality.
4. Describe the costs associated with quality.
5. Describe the quality awards.
6. Discuss the philosophies of quality gurus.
7. Describe TQM.
8. Give an overview of problem solving.
9. Give an overview of process improvement.
10. Describe and use various quality tools.

CHAPTER OUTLINE

This chapter is the first of two chapters on quality. In this chapter you will learn about the evolution of quality management, definitions of quality, the costs of quality and the consequences of poor quality, some quality awards and quality certification, total quality management, and quality tools.

INTRODUCTION

Broadly defined, **quality** refers to the ability of a product or service to consistently meet or exceed customer expectations. Prior to the increased level of Japanese competition in the U.S. marketplace in the 1970s and 1980s, quality was not uppermost in the minds of U.S. business organizations. They tended to focus more on cost and productivity rather than on quality. It wasn't that quality was *un*important, it just wasn't *very* important.

quality The ability of a product or service to consistently meet or exceed customer expectations.

Partly because of that thinking, foreign companies, many of them Japanese, captured a significant share of the U.S. market. In the automotive sector, leading Japanese manufacturers, Honda, Nissan, and Toyota, became major players in the auto sales market in the United States. Both Honda and Toyota built a reputation for quality and reliability in their cars.

www.honda.com

www.nissandriven.com

www.toyota.com

Many U.S. companies changed their views about quality after that, and changed them drastically. Stung by the success of foreign competitors, they embraced quality in a big way. They hired consultants, sent their people (including top executives) to seminars, and initiated a vast array of quality improvement programs. Those companies clearly recognized the importance of quality and that quality isn't something that is tacked on as a special feature, but an *integral part* of a product or service. By the 1990s, U.S. automakers began to close the quality gap.

THE EVOLUTION OF QUALITY MANAGEMENT

Prior to the Industrial Revolution, skilled craftsmen performed all stages of production. Pride of workmanship and reputation often provided the motivation to see that a job was done right.

Lengthy guild apprenticeships caused this attitude to carry over to new workers. Moreover, one person or a small group of people were responsible for an entire product.

A division of labor accompanied the Industrial Revolution; each worker was then responsible for only a small portion of each product. Pride of workmanship became less meaningful because workers could no longer identify readily with the final product. The responsibility for quality shifted to the foremen. Inspection was either nonexistent or haphazard, although in some instances 100 percent inspection was used.

Frederick Winslow Taylor, the "Father of Scientific Management," gave new emphasis to quality by including product inspection and gauging in his list of fundamental areas of manufacturing management. G. S. Radford improved Taylor's methods. Two of his most significant contributions were the notions of involving quality considerations early in the product design stage and making connections between high quality, increased productivity, and lower costs.

In 1924, Bell Telephone Laboratories introduced statistical control charts that could be used to monitor production. Around 1930, H. F. Dodge and H. G. Romig, also of Bell Labs, introduced tables for sampling. Nevertheless, statistical quality control procedures were not widely used until World War II, when the U.S. government began to require vendors to use them.

World War II caused a dramatic increase in emphasis on quality control. The U.S. Army refined sampling techniques for dealing with large shipments of arms from many suppliers. By the end of the 1940s, the U.S. Army, Bell Labs, and major universities were training engineers in other industries in the use of statistical sampling techniques. About the same time, professional quality organizations were emerging throughout the country. One of these organizations was the American Society for Quality Control (ASQC, now known as ASQ). Over the years, the society has promoted quality with its publications, seminars and conferences, and training programs.

During the 1950s, the quality movement evolved into quality assurance. In the mid-1950s, total quality control efforts enlarged the realm of quality efforts from its primary focus on manufacturing to also include product design and incoming raw materials. One important feature of this work was greater involvement of upper management in quality.

During the 1960s, the concept of "zero defects" gained favor. This approach focused on employee motivation and awareness, and the expectation of perfection from each employee. It evolved from the success of the Martin Company in producing a "perfect" missile for the U.S. Army.

In the 1970s, quality assurance methods gained increasing emphasis in services including government operations, health care, banking, and the travel industry.

Something else happened in the 1970s that had a global impact on quality. An embargo on oil sales instituted by OPEC (the Organization of Petroleum Exporting Countries) caused an increase in energy costs, and automobile buyers became more interested in fuel-efficient, lower-cost vehicles. Japanese auto producers, who had been improving their products, were poised to take advantage of these changes, and they captured an increased share of the automobile market. The quality of their automobiles enhanced the reputation of Japanese producers, opening the door for a wide array of Japanese-produced goods.

American producers, alarmed by their loss of market share, spent much of the late 1970s and the 1980s trying to improve the quality of their goods while lowering their costs.

The evolution of quality took a dramatic shift from quality assurance to a strategic approach to quality in the late 1970s. Up until that time, the main emphasis had been on finding and correcting defective products before they reached the market. It was still a reactive approach. The strategic approach is proactive, focusing on preventing mistakes from occurring altogether. Quality and profits are more closely linked. This approach also places greater emphasis on customer satisfaction, and it involves all levels of management as well as workers in a continuing effort to increase quality.

THE FOUNDATIONS OF MODERN QUALITY MANAGEMENT: THE GURUS

A core of quality pioneers shaped current thinking and practice. This section describes some of their key contributions to the field.

Walter Shewhart Walter Shewhart was a genuine pioneer in the field of quality control, and he became known as the "father of statistical quality control." He developed methods for analyzing the output of industrial processes to determine when corrective action was necessary. Shewhart had a strong influence on the thinking of two other gurus, W. Edwards Deming and Joseph Juran. While Shewhart's focus was primarily technical, Deming and Juran increased the focus to include managerial philosophy and responsibility.

W. Edwards Deming Deming, a statistics professor at New York University in the 1940s, went to Japan after World War II to assist the Japanese in improving quality and productivity. The Union of Japanese Scientists, who had invited Deming, were so impressed that in 1951, after a series of lectures presented by Deming, they established the **Deming Prize,** which is awarded annually to firms that distinguish themselves with quality management programs.

Deming Prize Prize established by the Japanese and awarded annually to firms that distinguish themselves with quality management programs.

Although the Japanese revered Deming, he was largely unknown to business leaders in the United States. In fact, he worked with the Japanese for almost 30 years before he gained recognition in his own country. Before his death in 1993, U.S. companies turned their attention to Deming, embraced his philosophy, and requested his assistance in setting up quality improvement programs.

Deming compiled a famous list of 14 points he believed were the prescription needed to achieve quality in an organization (see Table 9.1). His message was that the cause of inefficiency and poor quality is the *system,* not the employees. Deming felt that it was *management's responsibility* to correct the system to achieve the desired results. In addition to the 14 points, Deming stressed the need to reduce variation in output (deviation from a standard), which can be accomplished by distinguishing between *special causes* of variation (i.e., correctable) and *common causes* of variation (i.e., random).

The key elements of Deming's 14 points are constancy of purpose, continual improvement, and profound knowledge. *Profound knowledge* involves (1) an appreciation for a system, (2) a

TABLE 9.1
Deming's 14 points

1. Create constancy of purpose toward improvement of product and service with a plan to become competitive and to stay in business. Decide to whom top management is responsible.
2. Adopt the new philosophy. We are in a new economic age. We can no longer live with commonly accepted levels of delays, mistakes, defective materials, and defective workmanship.
3. Cease dependence on mass inspection. Require, instead, statistical evidence that quality is built in. (*Prevent* defects rather than *detect* defects.)
4. End the practice of awarding business on the basis of price tag. Instead, depend on meaningful measures of quality along with price. Eliminate suppliers that cannot qualify with statistical evidence of quality.
5. Find problems. It is management's job to work continually on the system (design, incoming materials, composition of material, maintenance, improvement of machine, training, supervision, retraining).
6. Institute modern methods of training on the job.
7. The responsibility of foremen must be changed from sheer numbers to quality . . . [which] will automatically improve productivity. Management must prepare to take immediate action on reports from foremen concerning barriers such as inherent defects, machines not maintained, poor tools, and fuzzy operational definitions.
8. Drive out fear, so that everyone may work effectively for the company.
9. Break down barriers between departments. People in research, design, sales, and production must work as a team to foresee problems of production that may be encountered with various materials and specifications.
10. Eliminate numerical goals, posters, and slogans for the work force, asking for new levels of productivity without providing methods.
11. Eliminate work standards that prescribe numerical quotas.
12. Remove barriers that stand between the hourly worker and his right to pride of workmanship.
13. Institute a vigorous program of education and retraining.
14. Create a structure in top management that will push every day on the above 13 points.

Source: Excerpt from "Out of the Crisis" by W. Edwards Deming. Copyright © 2000 MIT Press. Used with permission.

theory of variation, (3) a theory of knowledge, and (4) psychology. Deming's concept of profound knowledge incorporates the beliefs and values about learning that guided Japan's rise to a world economic power.

Appreciation for the system is the starting point, and it refers to everyone in the organization working to achieve optimization. Toward that end, management must eliminate internal competition. Reducing *variation* is an important key to quality improvement, but it is necessary to differentiate between random variation and correctable variation, and to focus on the latter. Deming believed that *knowledge* comes from theory, and that learning cannot occur within an organization without a theory of knowledge. Deming felt that *psychology* was the most powerful element of profound knowledge. He believed that workers want to create and learn, but that management unintentionally often does things such as establishing rating systems that rob them of their internal motivation. He believed that management's greatest challenge in achieving quality was in motivating workers to contribute their collective efforts to achieve a common goal. Last, Deming felt that in order to benefit from the concept of profound knowledge, it was necessary to embrace the concept in its entirety.

Joseph M. Juran Juran, like Deming, taught Japanese manufacturers how to improve the quality of their goods, and he, too, can be regarded as a major force in Japan's success in quality. He made his first trip to Japan a few years after the publication in 1951 of his *Quality Control Handbook.* Juran's approach to quality may be the closest to Deming's of all the gurus, although his approach differs on the importance of statistical methods and what an organization must do to achieve quality. Whereas Deming's work envisioned a "transformation," Juran believes that an organization can manage for quality. He doesn't think that managing quality is as difficult as Deming thought, although he does admit that most quality programs that fail do so because the companies do not realize how difficult developing new processes can be. Juran also places less emphasis on statistical methods than Deming. It is his view that quality begins by knowing what customers want.

Juran views quality as fitness-for-use. He also believes that roughly 80 percent of quality defects are management controllable; thus, management has the responsibility to correct this deficiency. He describes quality management in terms of a *trilogy* consisting of quality planning, quality control, and quality improvement. According to Juran, quality planning is necessary to establish processes that are *capable* of meeting quality standards; that quality control is necessary in order to know when corrective action is needed; and that quality improvement will help to find better ways of doing things. A key element of Juran's philosophy is the commitment of management to continual improvement.

Juran is credited as one of the first to measure the cost of quality, and he demonstrated the potential for increased profits that would result if the costs of poor quality could be reduced. Also, he made a series of videotapes entitled "Juran on Quality," which are available from the Juran Institute in Wilton, Connecticut.

Armand Feigenbaum Feigenbaum was instrumental in advancing the "cost of nonconformance" approach as a reason for management to commit to quality. At the age of 24, he was General Electric's top expert on quality. He recognized that quality was not simply a collection of tools and techniques, but a "total field." He saw that when improvements were made in a process, other areas of the company also achieved improvements. Feigenbaum's understanding of systems theory led him to create an environment in which people could learn from each other's successes, and his leadership and open work environment led to cross-functional teamwork.

In 1961, his book *Total Quality Control* was published, in which he layed out quality principles in 40 steps. According to Feigenbaum, it is the customer who defines quality. Deming would disagree; in his philosophy, companies should get to know their customers so well that they can anticipate their future needs.

Philip B. Crosby Crosby worked at Martin Marietta in the 1960s. While he was there, he developed the concept of *zero defects* and popularized the phrase "Do it right the first time." He stressed prevention, and he argued against the idea that "there will always be some level of defectives." He was the corporate vice president for quality for ITT in the 1970s and was instrumental in making quality a concern of top company executives. In 1979, his book *Quality Is Free* was published. The title is based on a quote from the CEO of ITT. The book explains quality concepts in simple terms.

In accordance with the concept of zero defects, Crosby believes that any level of defects is too high, and that management must install programs that help the organization move toward that goal. Among some of his key points are the following.[1]

1. Top management must demonstrate its commitment to quality and its willingness to give support to achieve good quality.
2. Management must be persistent in efforts to achieve good quality.
3. Management must spell out clearly what it wants in terms of quality and what workers must do to achieve that.
4. Make it (or do it) right the first time.

Unlike the other gurus, Crosby maintains that achieving quality can be relatively easy. His book *Quality without Tears: The Art of Hassle-Free Management* was published in 1984. The quality-is-free concept is that the costs of poor quality are much greater than traditionally defined. According to Crosby, these costs are so great that rather than viewing quality efforts as costs, organizations should view them as a way to reduce costs, because the improvements generated by quality efforts will more than pay for themselves.

Kaoru Ishikawa The late Japanese expert on quality was strongly influenced by both Deming and Juran, although he made significant contributions of his own to quality management. Among his key contributions were the development of the cause-and-effect diagram (also known as a fishbone diagram) for problem solving and the implementation of quality circles, which involve workers in quality improvement. He was the first quality expert to call attention to the *internal customer*—the next person in the process, the next operation, within the organization. He was a strong proponent of the need for companies to have a shared vision in order to unite everyone in the organization in a common goal, and he is widely recognized for his efforts to make quality control "user friendly" for workers.

Genichi Taguchi Taguchi is best known for the Taguchi loss function, which involves a formula for determining the cost of poor quality. The idea is that the deviation of a part from a standard causes a loss, and the combined effect of deviations of all parts from their standards can be large, even though each individual deviation is small. In contrast to Taguchi, Deming believed that it is impossible to determine the actual cost of the lack of quality, and Crosby believes that it would be difficult to apply the concept in most U.S. firms. Nonetheless, Taguchi's method is credited with helping the Ford Motor Company to reduce its warranty losses by achieving less variation in the output of transmissions.

Table 9.2 provides a summary of the important contributions of the gurus to modern quality management.

TABLE 9.2
A summary of key contributors to quality management

Contributor	Key Contributions
Shewhart	Control charts; variance reduction
Deming	14 points; special versus common causes of variation
Juran	Quality is fitness-for-use; quality trilogy
Feigenbaum	Quality is a total field; the customer defines quality
Crosby	Quality is free; zero defects
Ishikawa	Cause-and-effect diagrams; quality circles
Taguchi	Taguchi loss function

[1]Philip Crosby, *Quality without Tears: The Art of Hassle-Free Management* (New York: McGraw-Hill, 1984).

INSIGHTS ON QUALITY MANAGEMENT

Successful management of quality requires that managers have insights on various aspects of quality. These include defining quality in operational terms, understanding the costs and benefits of quality, recognizing the consequences of poor quality, and recognizing the need for ethical behavior. We begin with defining quality.

Defining Quality: The Dimensions of Quality

One way to think about quality is the degree to which performance of a product or service meets or exceeds customer expectations. The difference between these two, that is Performance–Expectations, is of great interest. If these two measures are equal, the difference is zero, and expectations have been met. If the difference is negative, expectations have not been met, whereas if the difference is positive, performance has exceeded customer expectations.

Customer expectations can be broken down into a number of categories, or *dimensions,* that customers use to judge the quality of a product or service. Understanding these helps organizations in their efforts to meet or exceed customer expectations. The dimensions used for goods are somewhat different than those used for services.

dimensions of quality Performance, aesthetics, special features, conformance, reliability, durability, perceived quality, and serviceability.

Product Quality Product quality is often judged on these eight **dimensions of quality.**[2]

Performance—main characteristics of the product or service.

Aesthetics—appearance, feel, smell, taste.

Special features—extra characteristics.

Conformance—how well a product or service corresponds to design specifications.

Reliability—consistency of performance.

Durability—the useful life of the product or service.

Perceived quality—indirect evaluation of quality (e.g., reputation).

Serviceability—handling of complaints or repairs.

These dimensions are further described by the examples presented in Table 9.3. When referring to a product, a customer sometimes judges the first four dimensions by its *fitness for use.*

Notice that price is *not* a dimension of quality.

TABLE 9.3
Examples of product quality dimensions for a car

Dimension	Examples
1. Performance	Everything works, fit and finish Ride, handling, acceleration
2. Aesthetics	Exterior and interior design
3. Features	Convenience: Placement of gauges High tech: Cell phone, dvd player Safety: anti-skid, airbags
4. Conformance	Car matches manufacturer's specifications
5. Reliability	Infrequent need for repairs
6. Durability	Useful life in miles, resistance to rust
7. Perceived quality	Top-rated
8. Serviceability	Service after sale

[2]Excerpt from David Garvin, "Competing on the Eight Dimensions of Quality," *Harvard Business Review* 65, no. 6 (1987), pp. 100–109. Reprinted by permission of Harvard Business Review,

Service Quality The dimensions of product quality don't adequately describe service quality. Instead, service quality is often described using these dimensions:[3]

Tangibles—the physical appearance of facilities, equipment, personnel, and communication materials.

Convenience—the availability and accessibility of the service.

Reliability—the ability to perform a service dependably, consistently, and accurately.

Responsiveness—the willingness of service providers to help customers in unusual situations and to deal with problems.

Time—the speed with which service is delivered.

Assurance—the knowledge exhibited by personnel who come into contact with a customer and their ability to convey trust and confidence.

Courtesy—the way customers are treated by employees who come into contact with them.

Table 9.4 illustrates how the dimensions of service quality might apply to having an automobile repaired.

The dimensions of both product and service quality establish a *conceptual* framework for thinking about quality, but even they are too abstract to be applied operationally for purposes of product or service design, or actually producing a product or delivering a service. They must be stated in terms of specific, *measurable* characteristics. For example, when buying a car, a customer would naturally be interested in the car's performance. But what does that mean? In more specific terms, it might refer to a car's estimated miles per gallon, how quickly it can go from 0 to 60 miles per hour, or its stopping distance when traveling at 60

At Motorola in Schaumburg, Illinois, new cell phones are put through the Dust Room and a variety of imaginative "torture" tests to ensure that they will endure the rigors of everyday use.

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TABLE 9.4
Examples of service quality dimensions for having a car repaired.

Dimension	Examples
1. Tangibles	Were the facilities clean? Were personnel neat?
2. Convenience	Was the service center conveniently located?
3. Reliability	Was the problem fixed?
4. Responsiveness	Were customer service personnel willing and able to answer questions?
5. Time	How long did the customer have to wait?
6. Assurance	Did the customer service personnel seem knowledgeable about the repair?
7. Courtesy	Were customer service personnel and the cashier friendly and courteous?

[3]Adapted from Valerie A. Zeithhaml, A. Parasuraman, and Leonard L. Berry, *Delivering Quality Service and Balancing Customer Expectations* (New York: The Free Press, 1990), and J. R. Evans and W. M. Lindsey, *The Management and Control of Quality,* 3rd ed. (St. Paul, MN: West Publishing, 1996).

mph. Each of these can be stated in measurable terms (e.g., estimated miles per gallon: city = 25, highway = 30). Similar measurable characteristics can often be identified for each of the other product dimensions, as well as for the service dimensions. This is the sort of detailed information that is needed to both design and produce high-quality goods and services.

Information on customer wants in service can sometimes be difficult to pin down, creating challenges for designing and managing service quality. For example customers may use words such as "friendly," "considerate," and "professional" to describe what they expect from service providers. These and similar descriptors are often difficult to translate into exact service specifications. Furthermore, in many instances, customer wants are often industry specific. Thus, the expectations for health care would be quite different than for dry cleaning. Furthermore, customer complaints may be due in part to unrelated factors (e.g., customer's mood or general health, the weather).

It should also be noted that in most instances, some quality dimensions of a product or service will be more important than others, so it is important to identify customer priorities, especially when it is likely that trade-off decisions will be made at various points in design and production. Quality function deployment (described in Chapter 4) is a tool that can be helpful for that purpose.

The Determinants of Quality

The degree to which a product or a service successfully satisfies its intended purpose has four primary determinants:

1. Design.
2. How well it conforms to the design.
3. Ease of use.
4. Service after delivery.

quality of design Intention of designers to include or exclude features in a product or service.

The design phase is the starting point for the level of quality eventually achieved. Design involves decisions about the specific characteristics of a product or service such as size, shape, and location. **Quality of design** refers to the intention of designers to include or exclude certain features in a product or service. For example, many different models of automobiles are on the market today. They differ in size, appearance, roominess, fuel economy, comfort, and materials used. These differences reflect choices made by designers that determine the quality of design. Design decisions must take into account customer wants, production or service capabilities, safety and liability (both during production and after delivery), costs, and other similar considerations.

Designers may determine customer wants from information provided by marketing, perhaps through the use of consumer surveys or other market research. Marketing may organize focus groups of consumers to express their views on a product or service (what they like and don't like, and what they would like to have).

Designers must work closely with representatives of operations to ascertain that designs can be produced; that is, that production or service has the equipment, capacity, and skills necessary to produce or provide a particular design.

A poor design can result in difficulties in production or service. For example, materials might be difficult to obtain, specifications difficult to meet, or procedures difficult to follow. Moreover, if a design is inadequate or inappropriate for the circumstances, the best workmanship in the world may not be enough to achieve the desired quality. Also, we cannot expect a worker to achieve good results if the given tools or procedures are inadequate. Similarly, a superior design usually cannot offset poor workmanship.

quality of conformance The degree to which goods or services conform to the intent of the designers.

Quality of conformance refers to the degree to which goods and services conform to (i.e., *achieve*) the intent of the designers. This is affected by factors such as the capability of equipment used; the skills, training, and motivation of workers; the extent to which the design lends itself to production; the monitoring process to assess conformance; and the taking of corrective action (e.g., through problem solving) when necessary. One important key to quality is reducing the variability in process outputs (i.e., reducing the degree to which individual items or individual service acts vary from one another). This will be discussed in detail in the following chapter.

The determination of quality does not stop once the product or service has been sold or delivered. *Ease of use* and user instructions are important. They increase the chances, but do not guarantee, that a product will be used for its intended purposes and in such a way that it will continue to function properly and safely. (When faced with liability litigation, companies often argue that injuries and damages occurred because the user misused the product.) Much of the same reasoning can be applied to services. Customers, patients, clients, or other users must be clearly informed on what they should or should not do; otherwise, there is the danger that they will take some action that will adversely affect quality. Some examples include the doctor who fails to specify that a medication should be taken *before* meals and *not* with orange juice and the attorney who neglects to inform a client of a deadline for filing a claim.

Much consumer education takes the form of printed instructions and labeling. Thus, manufacturers must ensure that directions for unpacking, assembling, using, maintaining, and adjusting the product—and what to do if something goes wrong (e.g., flush eyes with water, call a physician, induce vomiting, do not induce vomiting, disconnect set immediately)—are *clearly visible* and *easily understood.*

For a variety of reasons, products do not always perform as expected, and services do not always yield the desired results. Whatever the reason, it is important from a quality standpoint to remedy the situation—through recall and repair of the product, adjustment, replacement or buyback, or reevaluation of a service—and do whatever is necessary to bring the product or service up to standard.

The Consequences of Poor Quality

It is important for management to recognize the different ways that the quality of a firm's products or services can affect the organization and to take these into account in developing and maintaining a quality assurance program. Some of the major ways that quality affects an organization are

1. Loss of business
2. Liability
3. Productivity
4. Costs

Poor designs or defective products or services can result in *loss of business.* Failure to devote adequate attention to quality can damage a profit-oriented organization's image and lead to a decreased share of the market, or it can lead to increased criticism and/or controls for a government agency or nonprofit organization.

> A potentially . . . devastating consequence to the bottom line is the reaction of the consumer who receives a defective or otherwise unsatisfactory product or service. A recent study showed that, while a satisfied customer will tell a few people about his or her experience, a dissatisfied person will tell an average of 9 others.
>
> Unfortunately, the company is usually the last to know of dissatisfaction. People rarely complain directly to the provider of poor quality goods and services. In fact, studies suggest that people usually complain, if at all, to their most immediate contact (e.g., a salesperson or service manager) and that these complaints are rarely transmitted further. A more common response is simply to switch to a competing product or service. Typically, formal complaints are received from less than 5 percent of dissatisfied customers.[4]

Organizations must pay special attention to their potential *liability* due to damages or injuries resulting from either faulty design or poor workmanship. This applies to both products and services. Thus, a poorly designed steering arm on a car might cause the driver to lose control of the car, but so could improper assembly of the steering arm. However, the net result is

[4]The Ernst & Young Quality Improvement Consulting Group, *Total Quality: An Executive's Guide for the 1990s* (Homewood, IL: Irwin Professional Publishing: 1990), pp. 6–7.

the same. Similarly, a tree surgeon might be called to cable a tree limb. If the limb later falls and causes damage to a neighbor's car, the accident might be traced to a poorly designed procedure for cabling or to improper workmanship. Liability for poor quality has been well established in the courts. An organization's liability costs can often be substantial, especially if large numbers of items are involved, as in the automobile industry, or if potentially widespread injury or damage is involved (e.g., an accident at a nuclear power plant). Express written warranties as well as implied warranties generally guarantee the product as safe when used as intended. The courts have tended to extend this to *foreseeable* uses, even if these uses were not intended by the producer. In the health care field, medical malpractice claims and insurance costs are contributing to skyrocketing costs and have become a major issue nationwide.

Productivity and quality are often closely related. Poor quality can adversely affect productivity during the manufacturing process if parts are defective and have to be reworked or if an assembler has to try a number of parts before finding one that fits properly. Also, poor quality in tools and equipment can lead to injuries and defective output, which must be reworked or scrapped, thereby reducing the amount of usable output for a given amount of input. Similarly, poor service can mean having to redo the service and reduce service productivity.

Cost to remedy a problem is a major consideration in quality management. The earlier a problem is identified in the process, the cheaper the cost to fix it. It has been estimated that the cost to fix a problem at the customer end is about five times the cost to fix a problem at the design or production stages.

Medical Mistakes Kill Almost 98,000 a Year

NEWSCLIP

Medical mistakes kill tens of thousands of people a year, says a new report by the National Academy of Sciences.

The report said that medical errors kill nearly 98,000 people a year. This exceeds the number of people who die annually from highway accidents (about 43,450), breast cancer (42,300) or AIDS (16,500), the study said.

The group called for a new federal agency to protect patients and said that Congress should require all health care providers to report medical mistakes that cause serious injury or death. The panel said that the United States should strive to reduce medical errors by 50 percent in five years.

Errors range from a simple miscommunication about a drug's name between a doctor and a nurse to the erroneous programming of a complex medical device. They include wrong diagnoses from mislabeled blood tubes, mistaken treatments because of poorly labeled drugs and improper dosing because of faulty calculations.

Source: "Group Asking U.S. for New Vigilance in Patient Safety," Robert Pear, *New York Times*, Nov. 30, 1999, p. 1a.

Benefits of Good Quality

Business organizations with good or excellent quality typically benefit in a variety of ways: an enhanced reputation for quality, the ability to command premium prices, an increased market share, greater customer loyalty, lower liability costs, fewer production or service problems—which yields higher productivity, fewer complaints from customers, lower production costs, and higher profits. Annual studies by the National Institute of Standards indicate that winners of the Baldrige quality award, described later in the chapter, outperform the S&P 500 Index by a significant amount.[5]

Responsibility for Quality

It is true that all members of an organization have some responsibility for quality, but certain areas of the organization are involved in activities that make them key areas of responsibility. They include top management, design, procurement, production/operations, quality assurance, packaging and shipping, marketing and sales, and customer service.

[5] "'Baldrige Index' Outperforms S&P 500 by Almost 5 to 1," press release, available at www.quality.nist.gov/.

Top management. Top management has the ultimate responsibility for quality. While establishing strategies for quality, top management must institute programs to improve quality; guide, direct, and motivate managers and workers; and set an example by being involved in quality initiatives. Examples include taking training in quality, issuing periodic reports on quality, and attending meetings on quality.

Design. Quality products and services begin with design. This includes not only features of the product or service; it also includes attention to the *processes* that will be required to produce the products and/or the services that will be required to deliver the service to customers.

Procurement. The procurement department has responsibility for obtaining goods and services that will not detract from the quality of the organization's goods and services.

Production/operations. Production/operations has responsibility to ensure that processes yield products and services that conform to design specifications. Monitoring processes and finding and correcting root causes of problems are important aspects of this responsibility.

Quality assurance. Quality assurance is responsible for gathering and analyzing data on problems and working with operations to solve problems.

Packaging and shipping. This department must ensure that goods are not damaged in transit, that packages are clearly labeled, that instructions are included, that all parts are included, and shipping occurs in a timely manner.

Marketing and sales. This department has the responsibility to determine customer needs and to communicate them to appropriate areas of the organization. In addition, it has the responsibility to report any problems with products or services.

Customer service. Customer service is often the first department to learn of problems. It has the responsibility to communicate that information to appropriate departments, deal in a reasonable manner with customers, work to resolve problems, and follow up to confirm that the situation has been effectively remedied.

Poor quality increases certain *costs* incurred by the organization. The following section provides further detail on costs associated with quality.

The Costs of Quality

Any serious attempt to deal with quality issues must take into account the costs associated with quality. Those costs can be classified into three categories: appraisal, prevention, and failure.

Appraisal costs relate to inspection, testing, and other activities intended to uncover defective products or services, or to assure that there are none. They include the cost of inspectors, testing, test equipment, labs, quality audits, and field testing.

Prevention costs relate to attempts to prevent defects from occurring. They include costs such as planning and administration systems, working with vendors, training, quality control procedures, and extra attention in both the design and production phases to decrease the probability of defective workmanship.

Failure costs are incurred by defective parts or products or by faulty services. **Internal failures** are those discovered during the production process; **external failures** are those discovered after delivery to the customer. Internal failures occur for a variety of reasons, including defective material from vendors, incorrect machine settings, faulty equipment, incorrect methods, incorrect processing, carelessness, and faulty or improper material handling procedures. The costs of internal failures include lost production time, scrap and rework, investigation costs, possible equipment damage, and possible employee injury. Rework costs involve the salaries of workers and the additional resources needed to perform the rework (e.g., equipment, energy, raw materials). Beyond those costs are items such as inspection of reworked parts, disruption of schedules, the added costs of parts and materials in inventory waiting for reworked parts, and the paperwork needed to keep track of the items until they can be reintegrated into the process. External failures are defective products or poor service that go undetected by the producer.

appraisal costs Costs of activities designed to ensure quality or uncover defects.

prevention costs Costs of preventing defects from occurring.

failure costs Costs caused by defective parts or products or by faulty services.

internal failures Failures discovered during production.

external failures Failures discovered after delivery to the customer.

TABLE 9.5
Summary of quality costs

Category	Description	Examples
Appraisal costs	Costs related to measuring, evaluating, and auditing materials, parts, products, and services to assess conformance with quality standards	Inspection equipment, testing, labs, inspectors, and the interruption of production to take samples
Prevention costs	Costs related to reducing the potential for quality problems	Quality improvement programs, training, monitoring, data collection and analysis, and design costs
Internal failure costs	Costs related to defective products or services before they are delivered to customers	Rework costs, problem solving, material and product losses, scrap, and downtime
External failure costs	Costs related to delivering substandard products or services to customers	Returned goods, reworking costs, warranty costs, loss of goodwill, liability claims, and penalties

Resulting costs include warranty work, handling of complaints, replacements, liability/litigation, payments to customers or discounts used to offset the inferior quality, loss of customer goodwill, and opportunity costs related to lost sales.

External failure costs are typically much greater than internal failure costs on a per unit basis. Table 9.5 summarizes quality costs.

Internal and external failure costs represent costs related to poor quality, whereas appraisal and prevention costs represent investments for achieving good quality.

An important issue in quality management is the value received from expenditures on prevention. There are two schools of thought on this. One is that prevention costs will be outweighed by savings in appraisal and failure costs. This is espoused by such people as Crosby and Juran. They believe that as the costs of defect prevention are increased, the costs of appraisal and failure decrease by much more. What this means, if true, is that the net result is lower total costs, and, thus, as Crosby suggests, quality is free. On the other hand, some managers believe that attempting to go beyond a certain point, such expenditures on quality reduce the funds available for other objectives such as reducing product development times and upgrading technology. The **return on quality** (ROQ) approach focuses on the economics of quality efforts. In this approach, quality improvement projects are viewed as investments, and, as such, they are evaluated like any other investment, using metrics related to return on investment (ROI).

return on quality An approach that evaluates the financial return of investments in quality.

Ethics and Quality Management

All members of an organization have an obligation to perform their duties in an ethical manner. Ethical behavior comes into play in many situations that involve quality. One major category is substandard work, including defective products and substandard service, poor designs, shoddy workmanship, and substandard parts and raw materials. Having knowledge of this and failing to correct and *report it* in a timely manner is unethical and can have a number of negative consequences. These can include increased costs for organizations in terms of decreased productivity, an increase in the accident rate among employees, inconveniences and injuries to customers, and increased liability costs.

A related issue is how an organization chooses to deal with information about quality problems in products that are already in service. For example, automakers and tire makers in recent years have been accused of withholding information about actual or potential quality problems; they failed to issue product recalls, or failed to divulge information, choosing instead to handle any complaints that arose on an individual basis.

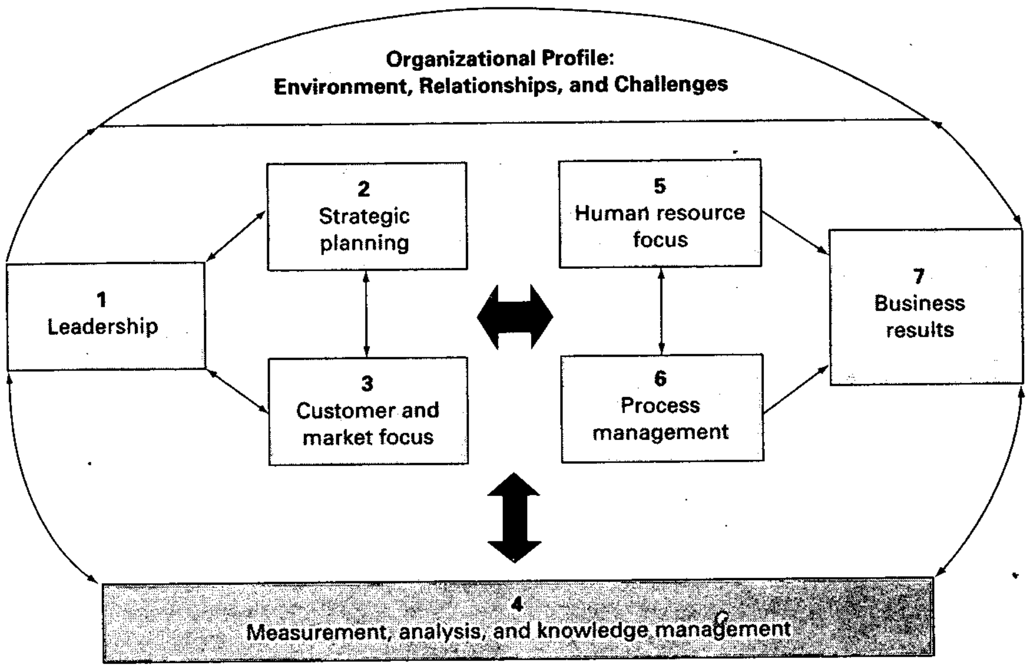

FIGURE 9.1

Baldrige criteria for performance excellence framework: A systems perspective

Source: www.quality.nist.gov.

QUALITY AWARDS

Quality awards have been established to generate awareness and interest in quality. The Malcolm Baldrige Award, the European Quality Award, and the Deming Prize are well-known awards given annually to recognize firms that have integrated quality management in their operations.

The Baldrige Award

In 1987, Congress passed the Malcolm Baldrige National Quality Improvement Act. This legislation was designed to inspire increased efforts on the part of organizations located in the United States to improve the quality of their products and services. Named after the late Malcolm Baldrige, an industrialist and former secretary of commerce, the annual **Baldrige Award** is administered by the National Institute of Standards and Technology.

Baldrige Award Annual award given by the U.S. government to recognize quality achievements of U.S. companies.

The purpose of the award competition is to stimulate efforts to improve quality, to recognize quality achievements, and to publicize successful programs. Awards are given annually in each of three categories: business, education, and health care.

Organizations that compete for the business award are required to submit an application of no more than 75 pages documenting their quality systems. Those who pass an initial screening must undergo a more intense evaluation by examiners from government and industry, and consultants. The examination includes an on-site visit. Applicants are evaluated in seven main areas: leadership, information and analysis, strategic planning, human resource management, customer and market focus, process management, and business results (see Figure 9.1). A key feature of the Baldrige competition is the "Core Values and Concepts" portion (see www.quality.gov for a complete description of award criteria and scoring). The current core values are summarized in the following reading.

Baldrige Core Values and Concepts

READING

The criteria for the Baldrige Award are related to a set of core values and concepts. These serve as a foundation for integrating key business requirements within a results-oriented framework. The core values and concepts are:

(continued)

Visionary Leadership

An organization's senior leaders need to set directions and create a customer focus, clear and visible values, and high expectations, balancing the needs of all stakeholders. Leaders need to ensure the creation of strategies, systems, and methods for achieving excellence, stimulating innovation, and building knowledge and capabilities.

Customer-Driven Excellence

Being customer driven is a strategic concept directed toward customer retention, market share gain, and growth. It includes not only defect and error reduction, meeting specifications, and reducing complaints, but also how well the organization is able to recover from defects and mistakes.

Organizational and Personal Learning

Organizational learning refers to continuous improvement of existing approaches and processes and adaptation to change, leading to new goals and/or approaches.

Organizations invest in employee personal learning through education, training, and opportunities for continuing growth. Opportunities might include job rotation and increased pay for demonstrated knowledge and skills.

Valuing Employees and Partners

Valuing employees means committing to their satisfaction, development, and well-being. Increasingly, this involves more flexible, high performance work practices tailored to employees with diverse workplace and home life needs. Major challenges in the area of valuing employees include (1) demonstrating your leaders' commitment to your employees; (2) providing recognition opportunities that go beyond the normal compensation system; (3) providing opportunities for development and growth within your organization; (4) sharing your organization's knowledge so your employees can better serve your customers and contribute to achieving your strategic objectives; and (5) creating an environment that encourages risk taking.

Organizations need to build internal and external partnerships to better accomplish overall goals. Internal partnerships might include labor–management cooperation, such as agreements with your unions. Partnerships with employees might entail employee development, cross-training, or new work organizations, such as high performance work teams. Internal partnerships also might involve creating network relationships among your work units to improve flexibility, responsiveness, and knowledge sharing.

External partnerships might be with customers, suppliers, and education organizations. Strategic partnerships or alliances are increasingly important kinds of external partnerships. Such partnerships might offer entry into new markets or a bias for new products or services. Also, partnerships might permit the blending of your organization's core competencies or leadership capabilities with the complementary strengths and capabilities of partners, thereby enhancing overall capability, including speed and flexibility.

Agility

Success in globally competitive markets demands creating a capacity for rapid change and flexibility. All aspects of electronic commerce require more rapid, flexible, and customized responses. Businesses face ever-shorter cycles for introductions of new or improved products and services. Faster and more flexible response to customers is now a more critical requirement. Major improvements in response time often require simplification of work units and processes and/or the ability for rapid changeover from one process to another. Cross-trained employees are vital assets in such a demanding environment.

Focus on the Future

Pursuit of sustainable growth and market leadership requires a strong future orientation and a willingness to make long-term commitments to key stakeholders . . . Major components of a future focus include developing employees and suppliers, seeking opportunities for innovation, and fulfilling public responsibilities.

Managing for Innovation

Innovation [should involve] making meaningful change to improve an organization's products, services, and processes and create new value for the organization's stakeholders. Innovation should focus on leading your organization to new dimensions of performance . . . Organizations should be structured in such a way that innovation becomes part of the culture and daily work.

Management by Fact

Data and analysis support a variety of purposes, such as planning, reviewing your overall performance, improving operations, and comparing your performance with competitors or with "best practices" benchmarks.

A major consideration in performance improvement involves the selection and use of performance measures or indicators.

Social Responsibility

An organization's leadership needs to stress its responsibilities to the public and needs to practice good citizenship. These responsibilities refer to basic expectations of your organization—business ethics and protection of public health, safety, and the environment. Health, safety, and the environment include your organization's operations as well as the life cycles of your products and services. Also, organizations need to emphasize resource conservation and waste reduction at the source. Planning should anticipate adverse impacts from production, distribution, transportation, use, and disposal of your products. Plans should seek to prevent problems, to provide a forthright response if problems occur, and to make available information

(continued)

(concluded)

and support needed to maintain public awareness, safety, and confidence. Organizations should not only meet all local, state, and federal laws and regulatory requirements, they should treat these and related requirements as opportunities for continuous improvement "beyond mere compliance."

Focus on Results and Creating Value

An organization's performance measurements need to focus on key results. Results should be focused on creating and balancing value for all your stakeholders—customers, employees, stockholders, suppliers and partners, the public, and the community . . . To meet the sometimes conflicting and changing aims that balancing value implies, organizational strategy needs to explicitly include all stakeholder requirements. This will help to ensure that actions and plans meet differing stakeholder needs and avoid adverse impacts on any stakeholders.

Systems Perspective

The Baldrige Criteria provide a systems perspective for managing your organization and achieving performance excellence. The core values and the seven Baldrige Categories form the building blocks of the system. However, successful management of the overall enterprise requires synthesis and alignment. Synthesis means looking at your organization as a whole and focusing on what is important to the whole enterprise. Alignment means concentrating on key organizational linkages among requirements given in the Baldrige Categories.

Criteria for Performance Excellence Framework

The Core Values and Concepts are embodied in seven categories, as follows:

1. Leadership (125 points)
2. Strategic Planning (85 points)
3. Customer and Market Focus (85 points)
4. Information and Analysis (85 points)
5. Human Resource Focus (85 points)
6. Process Management (85 points)
7. Business Results (450 points)

Source: Adapted from Criteria 2003 at the National Institute of Standards and Technology website: www.quality.nist.gov.

Examiners check the extent to which top management incorporates quality values in daily management; whether products or services are at least as good as those of competitors; whether employees receive training in quality techniques; if the business works with suppliers to improve quality; and if customers are satisfied. Even organizations that don't win benefit from applying for the award: All applicants receive a written summary of the strengths and weaknesses of their quality management and suggestions for improvement.

It is worthwhile to note that most states have quality award programs based on the Baldrige criteria. State awards are intended to recognize organizations within the state. These award programs can serve as an entry point for organizations that want to eventually apply for the national award.

Benefits of the Baldrige competition include

1. *Winners achieve financial success.* Studies have shown that the stock prices of publicly traded Baldrige winners do better than nonapplicants in the same industry, and better than the S&P 500 index.
2. *Winners share their knowledge.* Sharing information is a requirement of winners.
3. *The process motivates employees.* The process gets people involved in improving quality.
4. *The process provides a well-designed quality system.* The Baldrige criteria have been designed and are being continuously improved by quality and management experts.
5. *The process requires obtaining data.* The data produce facts that can be used to improve processes. Data include measurements of customer satisfaction, employee satisfaction, process performance, and supplier performance.
6. *The process provides feedback.* The feedback can be used for process improvement.

The European Quality Award

The **European Quality Award** is Europe's most prestigious award for organizational excellence. The European Quality Award sits at the top of regional and national quality awards and applicants have often won one or more of those awards prior to applying for the European Quality Award. There are four categories of awards, listed in descending order:

European Quality Award European award for organizational excellence.

Award winner. The European Quality Award is presented annually to the organization judged to be the best in each of the award categories, providing they also meet all the requirements set annually by the award jurors. Award winners are exceptional organizations—they are European or global role models in their approaches and the results they achieve.

Prize winners. Prizes are presented annually to organizations that excel in some of the fundamental concepts of excellence. These prizes are intended to identify role models. In 2003 there were special prizes in each category in the following areas:

- Leadership and constancy of purpose
- Customer focus
- Corporate social responsibility
- People development and involvement
- Results orientation

Finalists. Each year, several finalists may be declared in each category. Finalists are organizations that demonstrate a high degree of excellence in the management of quality as their fundamental process for continuous improvement.

Recognized for excellence. This indicates that the organization is well managed and aspires to achieve role model status.

Award winners, prize winners, and finalists are all recognized in ceremonies at a high-profile conference. Successful organizations at each level are entitled to use the award logo on letterheads, business cards, and advertisements. And all applicants receive detailed feedback on their assessment.

The Deming Prize

The Deming Prize, named in honor of the late W. Edwards Deming, is Japan's highly coveted award recognizing successful quality efforts. It is given annually to any company that meets the award's standards. Although typically given to Japanese firms, in 1989, Florida Power and Light became the first U.S. company to win the award.

The major focus of the judging is on statistical quality control, making it much narrower in scope than the Baldrige Award, which focuses more on customer satisfaction. Companies that win the Deming Prize tend to have quality programs that are detailed and well-communicated throughout the company. Their quality improvement programs also reflect the involvement of senior management and employees, customer satisfaction, and training.

Japan also has an additional award, the Japan Prize, fashioned roughly after the Baldrige Award.

QUALITY CERTIFICATION

Many firms that do business internationally recognize the importance of quality certification.

ISO 9000 and 14000

ISO 9000 A set of international standards on quality management and quality assurance, critical to international business.

ISO 14000 A set of international standards for assessing a company's environmental performance.

The International Organization for Standardization (ISO) promotes worldwide standards for the improvement of quality, productivity, and operating efficiency through a series of standards and guidelines. Two of the most well known of these are ISO 9000 and ISO 14000. **ISO 9000** pertains to quality management. It concerns what an organization does to ensure that its products or services conform to its customers' requirements. **ISO 14000** concerns what an organization does to minimize harmful effects to the environment caused by its operations. Both ISO 9000 and ISO 14000 relate to an organization's *processes* rather than its products and services, and stress continual improvement. Moreover, the standards are meant to be generic; no matter what the organization's business, if it wants to establish a quality management system or an environmental management system, the system must have the essential elements contained in ISO 9000 or in ISO 14000. The ISO 9000 standards are critical for companies doing business internationally, particularly in Europe. They must go through a process that involves documenting quality procedures and on-site assessment. The process often takes 12 to 18 months. With certification comes *registration* in an ISO directory that companies seeking suppliers can refer to for a list of certified companies. They are generally given preference over unregistered companies. More than 40,000 companies are registered worldwide; three-fourths of them are located in Europe.

A key requirement for registration is that a company review, refine, and map functions such as process control, inspection, purchasing, training, packaging, and delivery. Similar to the Baldrige Award, the review process involves considerable self-appraisal, resulting in problem identification and improvement. Unlike the Baldrige Award, registered companies face an ongoing series of audits, and they must be reregistered every three years.

In addition to the obvious benefits of certification for companies who want to deal with the European Union, the ISO 9000 certification and registration process is particularly helpful for companies that do not currently have a quality management system; it provides guidelines for establishing the system and making it effective.

ISO 9000 standards include the following categories:

System requirements
Management requirements
Resource requirements
Realization of requirements
Remedial requirements

Eight quality management principles form the basis of the latest version, ISO 9000 2000:

1. A systems approach to management.
2. Continual improvement.
3. Factual approach to decision making.
4. Mutually beneficial supplier relationships.
5. Customer focus.
6. Leadership.
7. People involvement.
8. Process approach.

The standards for ISO 14000 certification bear upon three major areas:

Management systems—Systems development and integration of environmental responsibilities into business planning.

Operations—Consumption of natural resources and energy.

Environmental systems—Measuring, assessing, and managing emissions, effluents, and other waste streams.

www.iso.org

www.asg.org

If you'd like to learn more about ISO standards, visit the International Organization for Standardization website at www.ISO.org/ISO/en/ISOonline.frontpage or the American Society for Quality website at www.asq.org/.

TOTAL QUALITY MANAGEMENT

A primary role of management is to lead an organization in its daily operation and to maintain it as a viable entity into the future. Quality has become an important factor in both of these objectives.

Although ostensibly always an objective of business, customer satisfaction, *in customer terms,* became a specific goal in the late 1980s. Providing high quality was recognized as a key element for success. Most large corporations taking that path have documented their success. First, they survived the strong overseas competition that had set the high quality levels and now have regained some of their former markets. Smaller companies are also adopting similar goals.

Management, with a new approach, played the critical role. The new approach is reflected in expressed changes in policy. The Ford Motor Company *operating philosophy* is a good example:

> The operating philosophy of Ford Motor Company is to meet customer needs and expectations by establishing and maintaining an environment which encourages all employees to pursue never-ending improvement in the quality and productivity of products and services throughout the corporation, its supply base, and its dealer organization.[6]

total quality management (TQM) A philosophy that involves everyone in an organization in a continual effort to improve quality and achieve customer satisfaction.

The term **total quality management (TQM)** refers to a quest for quality in an organization. There are three key philosophies in this approach. One is a never-ending push to improve, which is referred to as *continuous improvement;* the second is the *involvement of everyone* in the organization; and the third is a goal of *customer satisfaction,* which means meeting or exceeding customer expectations. TQM expands the traditional view of quality—looking only at the quality of the final product or services—to *looking at the quality of every aspect of the process* that produces the product or service. TQM systems are intended to prevent poor quality from occurring.

We can describe the TQM approach as follows:

1. Find out what customers want. This might involve the use of surveys, focus groups, interviews, or some other technique that integrates the customer's voice in the decision-making process. Be sure to include the *internal customer* (the next person in the process) as well as the *external customer* (the final customer).
2. Design a product or service that will meet (or exceed) what customers want. Make it easy to use and easy to produce.
3. Design processes that facilitate doing the job right the first time. Determine where mistakes are likely to occur and try to prevent them. When mistakes do occur, find out why so that they are less likely to occur again. Strive to make the process "mistake-proof." This is sometimes referred to as a **fail-safing:** Elements are incorporated in product or service design that make it virtually impossible for an employee (or sometimes a customer) to do something incorrectly. The Japanese term for this is *pokayoke.* Examples include parts that fit together one way only and appliance plugs that can be inserted into a wall outlet the correct way only. Another term that is sometimes used is *foolproofing,* but use of this term may be taken to imply that employees (or customers) are fools—not a wise choice!
4. Keep track of results, and use them to guide improvement in the system. Never stop trying to improve.
5. Extend these concepts to suppliers and distributors.

fail-safing Incorporating design elements that prevent incorrect procedures.

www.trekbikes.com

Many companies have successfully implemented TQM programs. Successful TQM programs are built through the dedication and combined efforts of everyone in the organization. Top management must be committed and involved. If it isn't, TQM will become just another fad that quickly dies and fades away.

The preceding description provides a good idea of what TQM is all about, but it doesn't tell the whole story. A number of other elements of TQM are important, including

continuous improvement Philosophy that seeks to make never-ending improvements to the process of converting inputs into outputs.

1. *Continuous improvement.* The *philosophy* that seeks to improve all factors related to the process of converting inputs into outputs on an ongoing basis is called **continuous improvement.** It covers equipment, methods, materials, and people. Under continuous improvement, the old adage "If it ain't broke, don't fix it" gets transformed into "Just because it isn't broke doesn't mean it can't be improved."

[6]Reprinted from Thomas J. Cartin, *Principles and Practices of TQM* (Milwaukee: ASQC Quality Press, 1993), p. 29.

The concept of continuous improvement was not new, but it did not receive much interest in the United States for a while, even though it originated here. However, many Japanese companies used it for years, and it became a cornerstone of the Japanese approach to production. The Japanese use the term **kaizen** to refer to continuous improvement. The successes of Japanese companies caused other companies to reexamine many of their approaches. This resulted in a strong interest in the continuous improvement approach.

kaizen Japanese term for continuous improvement.

2. *Competitive benchmarking.* This involves identifying other organizations that are the best at something and studying how they do it to learn how to improve your operation. The company need not be in the same line of business. For example, Xerox used the mail-order company L.L. Bean to benchmark order filling.

3. *Employee empowerment.* Giving workers the responsibility for improvements and the authority to make changes to accomplish them provides strong motivation for employees. This puts decision making into the hands of those who are closest to the job and have considerable insight into problems and solutions.

4. *Team approach.* The use of teams for problem solving and to achieve consensus takes advantage of group synergy, gets people involved, and promotes a spirit of cooperation and shared values among employees.

5. *Decisions based on facts rather than opinions.* Management gathers and analyzes data as a basis for decision making.

6. *Knowledge of tools.* Employees and managers are trained in the use of quality tools.

7. *Supplier quality.* Suppliers must be included in quality assurance and quality improvement efforts so that their processes are capable of delivering quality parts and materials in a timely manner.

8. *Champion.* A TQM champion's job is to promote the value and importance of TQM principles throughout the company.

9. *Quality at the source.* **Quality at the source** refers to the philosophy of making each worker responsible for the quality of his or her work. This incorporates the notions of "do it right" and "if it isn't right, fix it." Workers are expected to provide goods or services that meet specifications and to find and correct mistakes that occur. In effect, each worker becomes a quality inspector for his or her work. When the work is passed on to the next operation in the process (the internal customer) or, if that step is the last in the process, to the ultimate customer, the worker is "certifying" that it meets quality standards.

quality at the source The philosophy of making each worker responsible for the quality of his or her work.

This accomplishes a number of things: (1) it places direct responsibility for quality on the person(s) who directly affect it; (2) it removes the adversarial relationship that often exists between quality control inspectors and production workers; and (3) it motivates workers by giving them control over their work as well as pride in it.

Sign on the wall of a company cafeteria

> Sometimes they can be cranky, and it may sometimes seem like they expect too much, but they do provide our paychecks and our benefits, such as sick leave, maternity leave, health insurance, and three weeks of paid vacation time each year. And what about all the new equipment we've been getting lately? They pay for that, too. And a lot more. So the next time you see them, give them a great big smile to show how much you appreciate them—our *customers!*

10. *Suppliers* are partners in the process, and long-term relationships are encouraged. This gives suppliers a vital stake in providing quality goods and services. Suppliers, too, are expected to provide quality at the source, thereby reducing or eliminating the need to inspect deliveries from suppliers.

It would be incorrect to think of TQM as merely a collection of techniques. Rather, TQM reflects a whole new attitude toward quality. It is about the *culture* of an organization. To truly reap the benefits of TQM, the culture of an organization must change.

TABLE 9.6
Comparing the cultures of TQM and traditional organizations

Aspect	Traditional	TQM
Overall mission	Maximize return on investment	Meet or exceed customer expectations
Objectives	Emphasis on short term	Balance of long term and short term
Management	Not always open; sometimes inconsistent objectives	Open; encourages employee input; consistent objectives
Role of manager	Issue orders; enforce	Coach; remove barriers; build trust
Customer requirements	Not highest priority; may be unclear	Highest priority; important to identify and understand
Problems	Assign blame; punish	Identify and resolve
Problem solving	Not systematic; individuals	Systematic; teams
Improvement	Erratic	Continuous
Suppliers	Adversarial	Partners
Jobs	Narrow, specialized; much individual effort	Broad, more general; much team effort
Focus	Product oriented	Process oriented

Table 9.6 illustrates the differences between cultures of a TQM organization and a more traditional organization.

Six Sigma

six sigma A business process for improving quality, reducing costs, and increasing customer satisfaction.

The term **six sigma** has several meanings. Statistically, six sigma means having no more than 3.4 defects per million opportunities in any process, product, or service. Conceptually, the term is much broader, referring to a program designed to reduce the occurrence of defects to achieve lower costs and improved customer satisfaction. It is based on the application of certain tools and techniques to selected projects to achieve strategic business results. In the business world, six-sigma programs have become a key way to improve quality, save time, and cut costs. Six-sigma programs can be employed in design, production, service, inventory management, and delivery.

Motorola pioneered the concept of a six-sigma program in the 1980s. Since then, many other companies have developed their own six-sigma programs, including General Electric, Texas Instruments, Eastman Kodak, and Allied Signal.

There are management and technical components of six-sigma programs. The management component involves providing strong leadership, defining performance metrics, selecting projects likely to achieve business results, and selecting and training appropriate people. The technical component involves improving process performance, reducing variation, utilizing statistical methods, and designing a structured improvement strategy, which involves definition, measurement, analysis, improvement, and control.

For six sigma to succeed in any organization, buy-in at the top is essential. Top management must formulate and communicate the company's overall objectives and lead the program for a successful deployment. Other key players in six-sigma programs are program champions, "master black belts," "black belts," and "green belts." Champions identify and rank potential projects, help select and evaluate candidates, manage program resources, and serve as advocates for the program. Master black belts have extensive training in statistics and use of quality tools. They are teachers and mentors of black belts. Black belts are project team leaders responsible for implementing process improvement projects. They have typically completed four weeks of six-sigma training and have demonstrated mastery of the subject matter through an exam and successful completion of one or more projects. Green belts are members of project teams.

Black belts play a pivotal role in the success of six-sigma programs. They influence change, facilitate teamwork, provide leadership in applying tools and techniques, and convey knowledge and skills to green belts. Black belt candidates generally have a proven strength in either a technical discipline such as engineering or a business discipline. Candidates also must have strong "people skills" and be able to facilitate change. And they must be proficient in applying continuous improvement and statistical methods and tools. A black belt must understand the technical aspects of process improvement as well as the expected business results (time, money, quality improvement).

A six-sigma improvement project typically has one or more objectives such as reducing defects, reducing costs, reducing product and/or process variability, reducing delivery time, increasing productivity, or improving customer satisfaction. The process is to define, measure, analyze, improve, and control (DMAIC). The projects involve the use of management science tools as well as statistical tools.[7]

Obstacles to Implementing TQM

Companies have had varying success in implementing TQM. Some have been quite successful, but others have struggled. Part of the difficulty may be with the process by which it is implemented rather than with the principles of TQM. Among the factors cited in the literature are

1. Lack of a companywide definition of quality: Efforts aren't coordinated; people are working at cross-purposes, addressing different issues, using different measures of success.
2. Lack of a strategic plan for change: Lessens the chance of success; ignores need to address strategic implications of change.
3. Lack of a customer focus: Without this, there is a risk of customer dissatisfaction.
4. Poor intraorganizational communication: The left hand doesn't know what the right hand is doing; frustration, waste, and confusion ensue.
5. Lack of employee empowerment: Gives the impression of not trusting employees to fix problems; adds "red tape" and delays solutions.
6. View of quality as a "quick fix": Needs to be a long-term, continuing effort.
7. Emphasis on short-term financial results: "Duct-tape" solutions often treat symptoms; spend a little now—a lot more later.
8. Inordinate presence of internal politics and "turf" issues: These can sap the energy of an organization and derail the best of ideas.
9. Lack of strong motivation: Managers need to make sure employees are motivated.
10. Lack of time to devote to quality initiatives: Don't add more work without adding additional resources.
11. Lack of leadership:[8] Managers need to be leaders.

This list of potential problems can serve as a guideline for organizations contemplating implementing TQM or as a checklist for those having trouble implementing it.

What Keeps Six Sigma Practitioners Up At Night?

READING

Bill Kowalski

Recent Survey Shows Need for an Expanded Toolkit

It may be the most widely acclaimed performance improvement system across the business world, yet Six Sigma is not immune to a paradox common to most large-scale change efforts:

> *You can't expect to sustain top executive support without producing consistent bottom-line results . . . yet consistent results aren't likely without sustained top executive support.*

This conundrum is a key finding from a recent survey of more than 240 Six Sigma practitioners across industries and around the globe. Sponsored by Leap Technologies, the survey was conducted anonymously over the web through iSixSigma.com, the leading Six Sigma information portal.

The survey gauged perceptions of Six Sigma practitioners on two primary issues:

(continued)

[7]S. L. Ahire, "The Management Science—Total Quality Management Interfaces: An Integrative Framework," *Interfaces* 27, no. 6 (1997), pp. 91–114.

[8]Gary Salegna and Farzaneh Fazel, "Obstacles to Implementing Quality," *Quality Progress*, July 2000, p. 53.

(concluded)

1. What causes Six Sigma projects to fail to produce desired results?
2. What would most help to improve Six Sigma project results?

We know these are issues keeping practitioners up at night because these same people are under increasingly heavy pressure to produce and sustain bottom-line results from their projects.

The "CATCH 22" For Six Sigma Practitioners

The most often cited reason for Six Sigma project failure was "lack of sustained executive sponsorship and commitment." It is clearly evident that there is no substitute for top leadership support to achieve sustained Six Sigma success. In close second ranking was "lack of buy-in, cooperation and ownership by frontline managers and employees for implementing and sustaining results on Six Sigma project solutions." These top two barriers to success create a classic "Catch 22" for Six Sigma practitioners. On the one hand, executive commitment is critical to the funding and mandate Six Sigma practitioners need to challenge the status quo.

On the other hand, sustaining executive support is nearly impossible without consistent delivery of results. Yet this payoff can't be sustained without active support by those most impacted by Six Sigma solutions . . . *frontline managers and employees!*

Six Sigma is, with its dedicated Belt infrastructure and standardized *DMAIC methodology,* a more sophisticated and effective approach than past quality improvement methods. But, if there is a chink to be found in Six Sigma's armor, it is the issue of non-Belt participation and ownership. This problem, however, rarely surfaces in the first 12 to 18 months of a *Six Sigma Deployment.* In fact, we've observed that, initially, many Six Sigma Deployment Leaders experience a false sense of security about results. Why? Because most of the projects taken on by newly trained Black and Green Belts rarely require high levels of frontline support and, for the most part, don't challenge top management's ingrained cultural biases.

At the same time, it's also not uncommon for organizations adopting Six Sigma to "hit the wall" once "low touch" projects are completed. Top management's appetite for results has been whetted, but the foundational support in terms of skills, experience and commitment may not be there to tackle the projects that present bigger change management challenges.

More Tools Are Needed

According to the Six Sigma practitioners completing the survey, the path to better Six Sigma project results requires equipping practitioners with an expanded set of tools to both tackle more complex projects and improve Belt productivity by getting more non-Belt involvement. This finding is not likely to be a revelation to many of the early pioneers who paved the way to the popularity of Six Sigma. Companies like Motorola, Allied Signal (now merged with Honeywell) and GE, along with other big players, such as DuPont, and 3M (among others), have already taken steps to strengthen their Six Sigma Deployments by enhancing the skills of Belts and expanding the tool kit.

At the same time, the survey results indicate there is more work to do in advancing Six Sigma into a robust and sustainable method for *transformational change.* The top priority appears to be the expansion of the Six Sigma practitioner's tool kit to break free of the "Catch 22" syndrome. In fact, the integration of *Lean principles* by numerous Six Sigma users is a big step in the right direction. However, in addition to Lean tools there also appears to be a growing recognition that more tools are needed to deal with the *change management* aspects of Six Sigma. Ninety percent of the survey respondents rated the need for a structured tool set for engaging "non-Belts" in projects, particularly those with significant behavior change requirements.

The preceding finding is linked to the second most important reason practitioners stated as the cause for Six Sigma projects falling short (i.e., lack of buy-in, cooperation or ownership by frontline employees and managers). The relationship between these two findings correlates with the anecdotal evidence from more experienced Six Sigma organizations about the keys to accelerating results and reducing project cycle times. As they move down the experience curve and tackle larger and more complex change projects, the most successful Six Sigma organizations have expanded their tool sets and integrated other improvement disciplines such as Lean seamlessly into deployments.

The Keys to a Better Night's Sleep

Six Sigma practitioners can break free of the "Catch 22" syndrome by designing their deployments to deliver consistent results and sustain consistent executive support. The keys are:

1. Expand the tool set early in deployment with methods to get more non-Belt participation and faster results. The key to avoiding confusion or overload is to integrate Lean, Innovation, and other improvement methods into the DMAIC framework.
2. Engage senior leaders to go beyond the rubber-stamping of project selections to actually designing the project plan with the Belts. The benefits are a more realistic appraisal of project requirements and deeper understanding of where and how to apply other tool sets to drive bigger and faster results.
3. Engage non-Belt managers and employees early on projects where there is existing motivation for change.

Taking actions such as these will provide a steadier stream of results, sustained executive support and, ensure a better night's sleep for Six Sigma practitioners!

Source: "What Keeps Six Sigma Practitioners Up at Night?" by Bill Kowalski

About The Author

Bill Kowalski is a Senior Partner with Leap Technologies, the leading provider of Change Acceleration Tools for Six Sigma Deployment. For more articles and information on accelerating organization change, Visit Leap Technologies on the web at www.actionworkout.com.

Criticisms of TQM

TQM programs are touted as a way for companies to improve their competitiveness, which is a very worthwhile objective. Nonetheless, TQM programs are not without criticism. Some of the major ones are

1. Blind pursuit of TQM programs: Overzealous advocates may focus attention on quality even though other priorities may be more important (e.g., responding quickly to a competitor's advances).
2. Programs may not be linked to the strategies of the organization in a meaningful way.
3. Quality-related decisions may not be tied to market performance. For instance, customer satisfaction may be carried to the extent that its cost far exceeds any direct or indirect benefit of doing so.
4. Failure to carefully plan a program before embarking on it can lead to false starts, employee confusion, and meaningless results.

Quality Programs Don't Guarantee Results — READING

U.S. companies have poured millions of dollars into quality programs in the last few years. Unfortunately, the programs do not always achieve the results companies expect. The McKinsey Consulting Group has developed several useful guidelines for executives concerning quality programs:

Don't promote continuous improvement if dramatic results are needed. Sagging sales and profits often imply the need for something more than incremental improvement. Continuous improvement programs should be reserved for those instances where an organization has already achieved substantial quality results but still wants to improve its operations.

Link quality programs to strategic planning. Then, set goals for the program, and evaluate senior management, based on how well those goals are met. However, let lower-level employees set their own goals in order to get them involved, and to motivate their best performance.

Focus programs on market "break points." Customers may not be able to perceive a difference between an on-time delivery performance of 90 percent and one of, say, 95 percent, although they would perceive a difference between 90 percent and 99 percent on-time delivery. So determine what the break points are, and don't waste resources on improving performance that does not achieve a higher break point.

Choose a single theme. It is important for everybody to be rowing in the same direction. Note, however, that a single focus does carry a risk: It may become an end in itself.

Emphasize results as well as the process. Focusing exclusively on the process carries the risk of diverting attention from results, and may also lead to excessive buildup in staff associated with the program. Instead, set specific goals in terms of *measurable* results.

Questions

1. List some of the ways a company can judge whether its quality program is working.
2. Explain the importance of measurements for quality programs.
3. For each guideline, explain the rationale.

Source: Based on "When Quality Control Gets in the Way of Quality," by Graham Sharman, *The Wall Street Journal*, ©1992.

Note that there is nothing inherently wrong with TQM; the problem is how some individuals or organizations misuse it. Let's turn our attention to problem solving and process improvement.

PROBLEM SOLVING

Problem solving is one of the basic procedures of TQM. In order to be successful, problem-solving efforts should follow a standard approach. Table 9.7 describes the basic steps in the TQM problem-solving process.

An important aspect of problem solving in the TQM approach is *eliminating* the cause so that the problem does not recur. This is why users of the TQM approach often like to think of problems as "opportunities for improvement."

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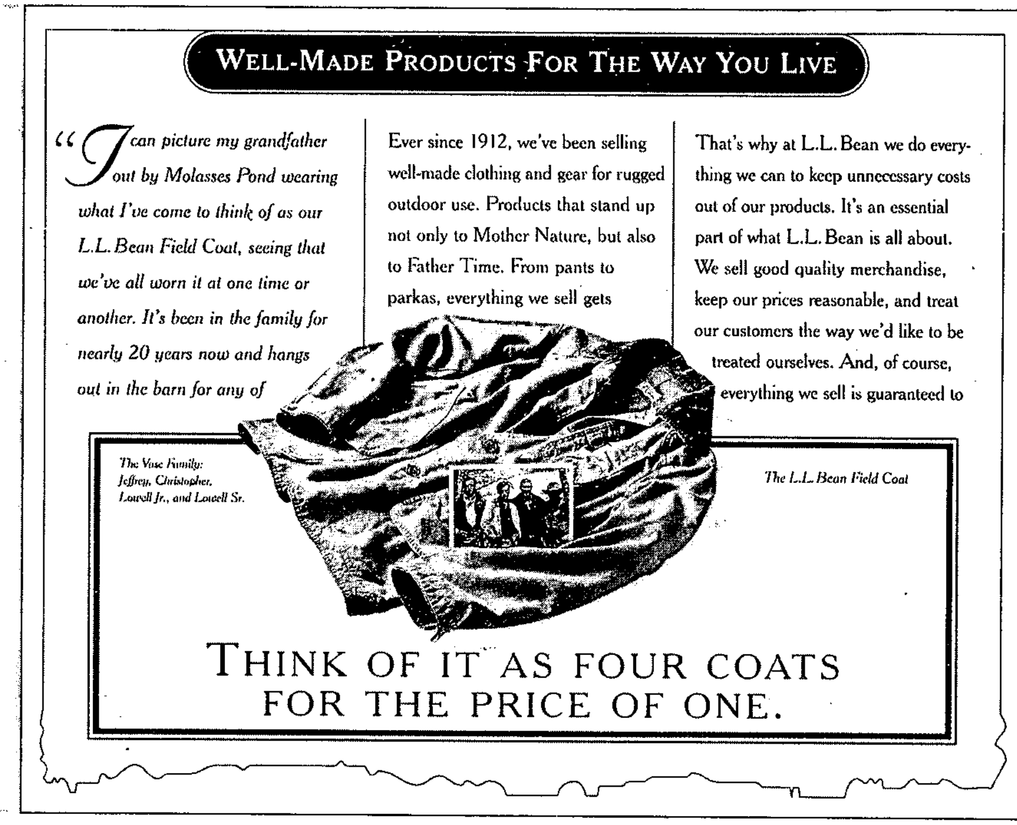


TABLE 9.7
Basic steps in problem solving

Step 1	**Define the problem and establish an improvement goal.** Give problem definition careful consideration; don't rush through this step because this will serve as the focal point of problem-solving efforts.
Step 2	**Develop performance measures and collect data.** The solution must be based on *facts.* Possible tools include check sheet, scatter diagram, histogram, run chart, and control chart.
Step 3	**Analyze the problem.** Possible tools include Pareto chart, cause-and-effect diagram.
Step 4	**Generate potential solutions.** Methods include brainstorming, interviewing, and surveying.
Step 5	**Choose a solution.** Identify the criteria for choosing a solution. (Refer to the goal established in Step 1.) Apply criteria to potential solutions and select the best one.
Step 6	**Implement the solution.** Keep everyone informed.
Step 7	**Monitor the solution to see if it accomplishes the goal.** If not, modify the solution, or return to Step 1. Possible tools include control chart and run chart.

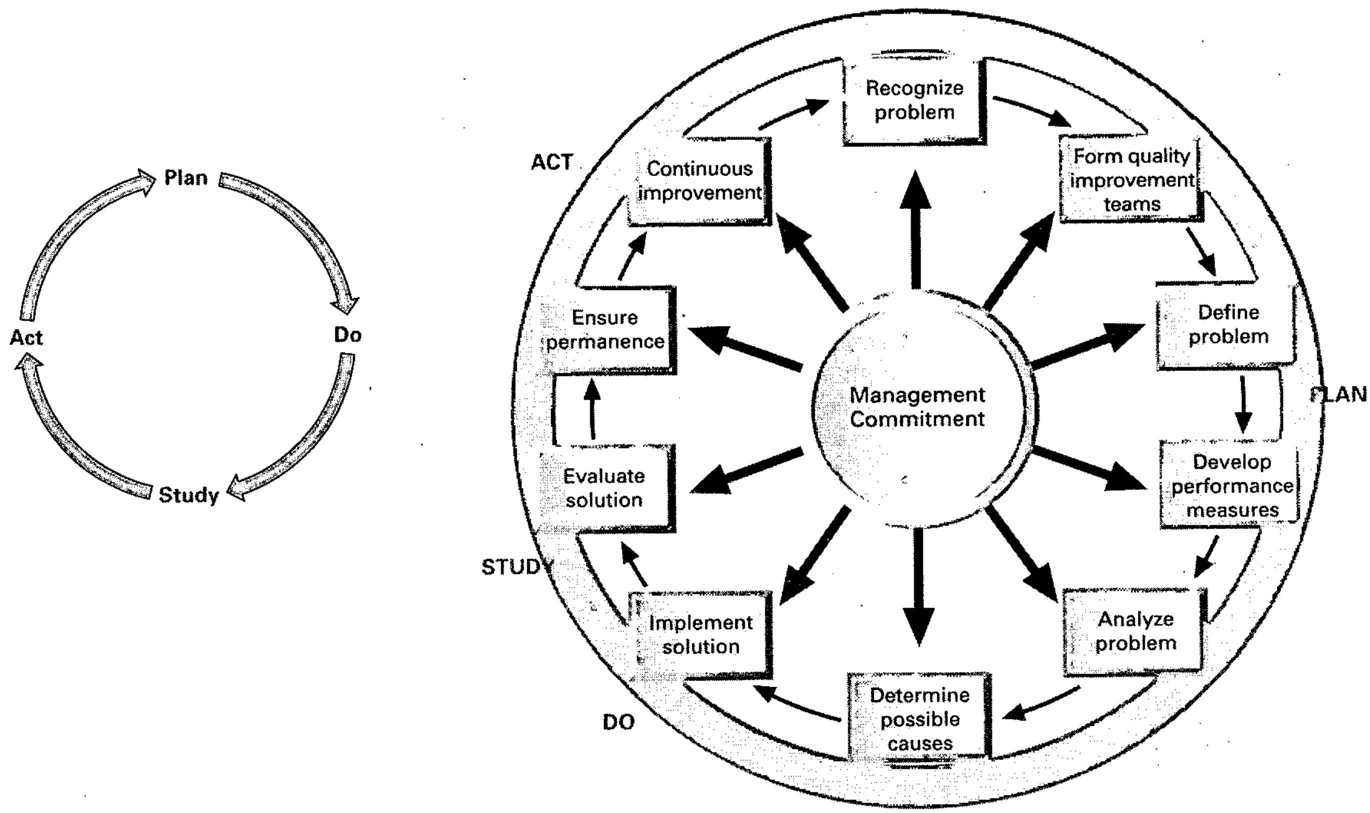
plan-do-study-act (PDSA) cycle A framework for problem solving and improvement activities.

The Plan-Do-Study-Act Cycle

The **plan-do-study-act (PDSA) cycle,** also referred to as either the Shewhart cycle or the Deming wheel, is the conceptual basis for problem-solving activities. The cycle is illustrated in Figure 9.2. Representing the process with a circle underscores its continuing nature.

FIGURE 9.2

A. The PDSA cycle B. The PDSA cycle applied to problem solving



Source: Figure from *Quality,* 2/e, Donna Summers. Copyright © 2000 Prentice Hall, Inc. Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ., p. 67.

There are four basic steps in the cycle:

Plan. Begin by studying the current process. Document that process. Then collect data on the process or problem. Next, analyze the data and develop a plan for improvement. Specify measures for evaluating the plan.

Do. Implement the plan, on a small scale if possible. Document any changes made during this phase. Collect data systematically for evaluation.

Study. Evaluate the data collection during the *do* phase. Check how closely the results match the original goals of the *plan* phase.

Act. If the results are successful, *standardize* the new method and communicate the new method to all people associated with the process. Implement training for the new method. If the results are unsuccessful, revise the plan and repeat the process or cease this project.

In replicating successful results elsewhere in the organization, the cycle is repeated. Similarly, if the plan was unsuccessful and you wish to make further modifications, repeat this cycle.

Employing this sequence of steps provides a systematic approach to continuous improvement.

PROCESS IMPROVEMENT

process improvement A systematic approach to improving a process.

Process improvement is a *systematic* approach to improving a process. It involves documentation, measurement, and analysis for the purpose of improving the functioning of a process. Typical goals of process improvement include increasing customer satisfaction, achieving higher quality, reducing waste, reducing cost, increasing productivity, and reducing processing time.

Table 9.8 provides an overview of process improvement, and Figure 9.3 shows its cyclical nature.

TABLE 9.8
Overview of process improvement

A. Process mapping

1. Collect information about the process; identify each step in the process. For each step, determine:
   The inputs and outputs.
   The people involved.
   The decisions that are made.
   Document such measures as time, cost, space used, waste, employee morale and any employee turnover, accidents and/or safety hazards, working conditions, revenues and/or profits, quality, and customer satisfaction, as appropriate.
2. Prepare a flowchart that *accurately* depicts the process; note that too little detail will not allow for meaningful analysis, and too much detail will overwhelm analysts and be counterproductive. Make sure that key activities and decisions are represented.

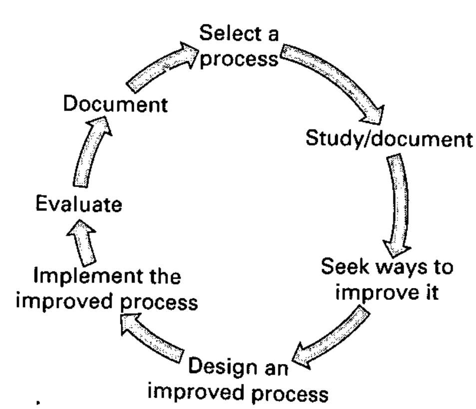
B. Analyze the process

1. Ask these questions about the process:
   Is the flow logical?
   Are any steps or activities missing?
   Are there any duplications?
2. Ask these questions about each step:
   Is the step necessary? Could it be eliminated?
   Does the step add value?
   Does any waste occur at this step?
   Could the time be shortened?
   Could the cost to perform the step be reduced?
   Could two (or more) steps be combined?

C. Redesign the process

Using the results of the analysis, redesign the process. Document the improvements; potential measures include reductions in time, cost, space, waste, employee turnover, accidents, safety hazards, and increases/improvements in employee morale, working conditions, revenues/profits, quality, and customer satisfaction.

FIGURE 9.3
The process improvement cycle is another version of the plan-do-study-act cycle



QUALITY TOOLS

There are a number of tools that an organization can use for problem solving and process improvement. This section describes eight of these tools. The tools aid in data collection and interpretation, and provide the basis for decision making.

The first seven tools are often referred to as the *seven basic quality tools.* Figure 9.4 provides a quick overview of the seven tools.

Flowcharts A **flowchart** is a visual representation of a process. As a problem-solving tool, a flowchart can help investigators in identifying possible points in a process where problems occur. Figure 9.5 (on page 409) illustrates a flowchart.

flowchart A diagram of the steps in a process.

The diamond shapes in the flowchart represent decision points in the process, and the rectangular shapes represent procedures. The arrows show the direction of "flow" of the steps in the process.

To construct a simple flowchart, begin by listing the steps in a process. Then classify each step as either a procedure or a decision (or check) point. Try to not make the flowchart too detailed, or it may be overwhelming, but be careful not to omit any key steps.

Check Sheets A **check sheet** is a simple tool frequently used for problem identification. Check sheets provide a format that enables users to record and organize data in a way that facilitates collection and analysis. This format might be one of simple checkmarks. Check sheets are designed on the basis of what the users are attempting to learn by collecting data.

check sheet A tool for recording and organizing data to identify a problem.

Many different formats can be used for a check sheet and there are many different types of sheets. One frequently used form of check sheet deals with type of defect, another with location of defects. These are illustrated in Figures 9.6 and 9.7 (on pages 409 and 410).

Figure 9.6 shows tallies that denote the type of defect and the time of day each occurred. Problems with missing labels tend to occur early in the day and smeared print tends to occur late in the day, whereas offcenter labels are found throughout the day. Identifying types of defects and when they occur can help in pinpointing causes of the defects.

Figure 9.7 makes it easy to see where defects on the product are occurring. In this case, defects seem to be occurring on the tips of the thumb and first finger, in the finger valleys (especially between the thumb and first finger), and in the center of the gloves. Again, this may help determine why the defects occur and lead to a solution.

Histograms A **histogram** can be useful in getting a sense of the distribution of observed values. Among other things, one can see if the distribution is symmetrical, what the range of values is, and if there are any unusual values. Figure 9.8 (on page 410) illustrates a histogram. Note the two peaks. This suggests the possibility of *two* distributions with different centers. Possible causes might be two workers or two suppliers with different quality.

histogram A chart of an empirical frequency distribution.

Pareto Analysis **Pareto analysis** is a technique for focusing attention on the most important problem areas. The Pareto concept, named after the nineteenth-century Italian economist Vilfredo Pareto, is that a relatively few factors generally account for a large percentage of the total cases (e.g., complaints, defects, problems). The idea is to classify the cases according to degree of importance, and focus on resolving the most important, leaving the less important. Often referred to as the 80–20 rule, the Pareto concept states that approximately 80 percent of the problems come from 20 percent of the items. For instance, 80 percent of machine breakdowns come from 20 percent of the machines, and 80 percent of the product defects come from 20 percent of the causes of defects.

Pareto analysis Technique for classifying problem areas according to degree of importance, and focusing on the most important.

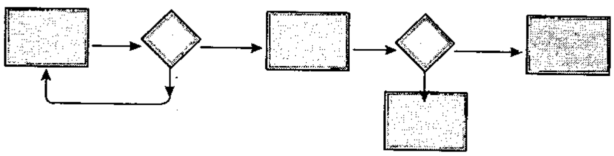
IOM

Often, it is useful to prepare a chart that shows the number of occurrences by category, arranged in order of frequency. Figure 9.9 illustrates such a chart corresponding to the check sheet shown in Figure 9.6. The dominance of the problem with offcenter labels becomes apparent. Presumably, the manager and employees would focus on trying to resolve this problem. Once they accomplished that, they could address the remaining defects in similar fashion; "smeared print" would be the next major category to be resolved, and so on. Additional check

FIGURE 9.4

The seven basic quality tools

Flowchart



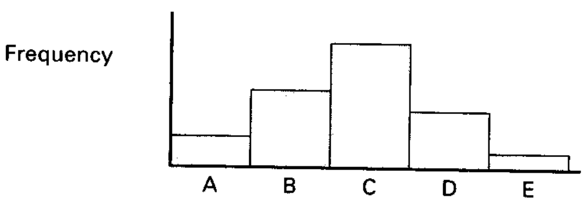
A diagram of the steps in a process

Check sheet

Defect	Day 1	Day 2	Day 3	Day 4
A	///		////	/
B	//	/	//	///
C	/	////	//	////

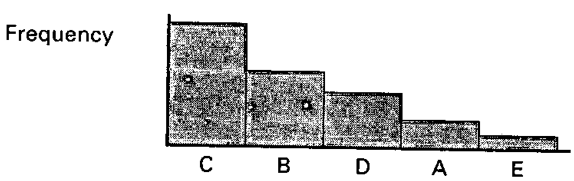
A tool for organizing and collecting data; a tally of problems or other events by category

Histogram



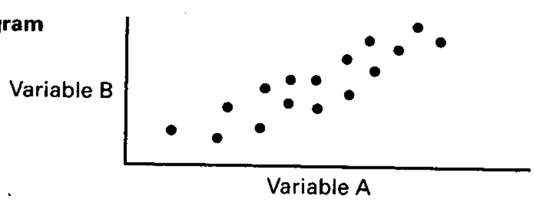
A chart that shows an empirical frequency distribution

Pareto chart



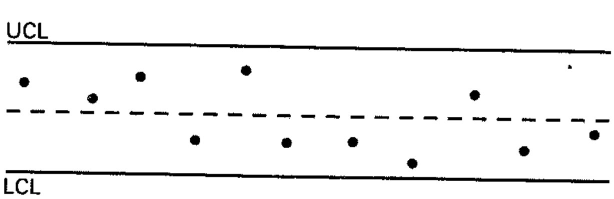
A diagram that arranges categories from highest to lowest frequency of occurrence

Scatter diagram



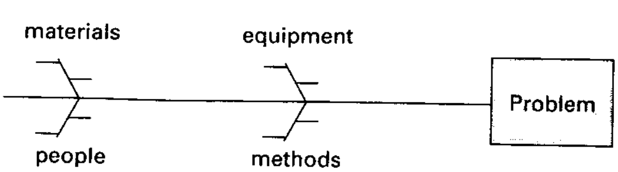
A graph that shows the degree and direction of relationship between two variables

Control chart



A statistical chart of time-ordered values of a sample statistic (e.g., sample means)

Cause–and–effect diagram



A diagram used to organize a search for the cause(s) of a problem; also known as a *fishbone* diagram

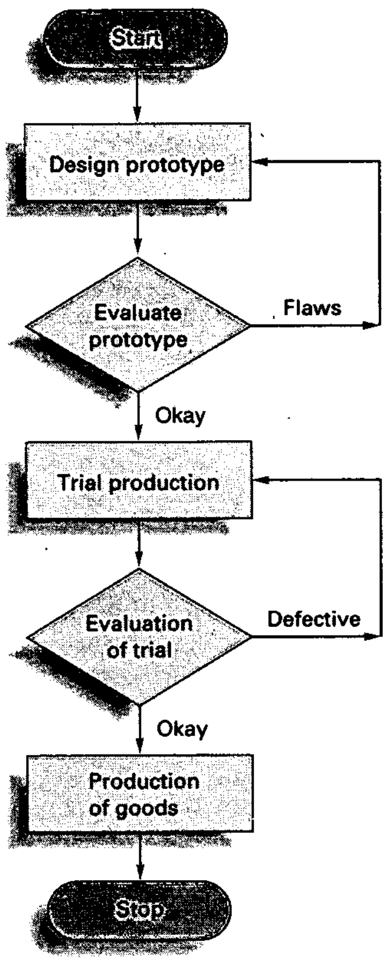


FIGURE 9.5

A flowchart

Day	Time	Type of Defect: Missing label	Off-center	Smeared print	Loose or folded	Other	Total
M	8-9	IIII	II				6
	9-10		III				3
	10-11	I	III	I			5
	11-12		I		I	I(Torn)	3
	1-2		I				1
	2-3		II	III	I		6
	3-4		II	~~IIII~~I			8
Total		5	14	10	2	1	32

FIGURE 9.6

An example of a check sheet

sheets would be used to collect data to verify that the defects in these categories have been eliminated or greatly reduced. Hence, in later Pareto diagrams, categories such as "offcenter" may still appear but would be much less prominent.

Scatter Diagrams A **scatter diagram** can be useful in deciding if there is a correlation between the values of two variables. A correlation may point to a cause of a problem. Figure 9.10 shows an example of a scatter diagram. In this particular diagram, there is a *positive* (upward sloping) relationship between the humidity and the number of errors per hour. High values of

scatter diagram A graph that shows the degree and direction of relationship between two variables.

FIGURE 9.7

A special purpose check sheet

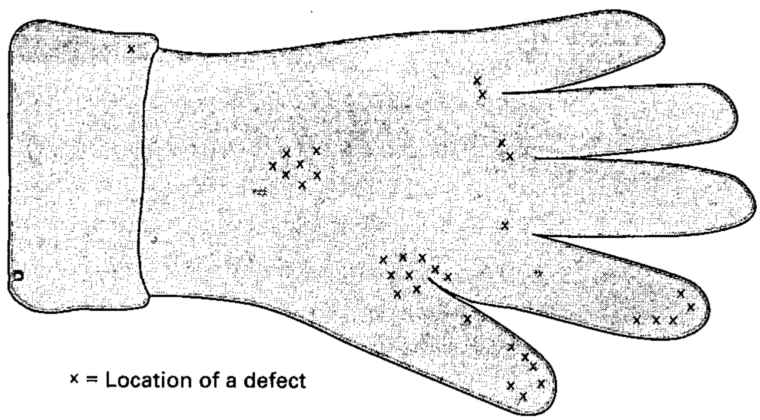


FIGURE 9.8

A histogram

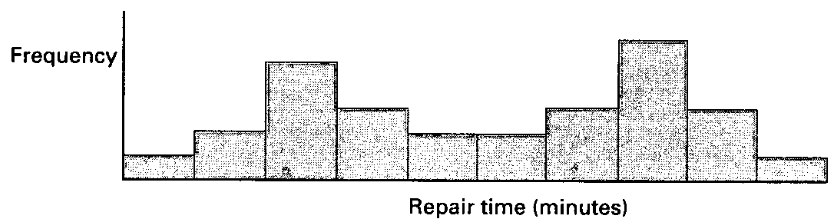
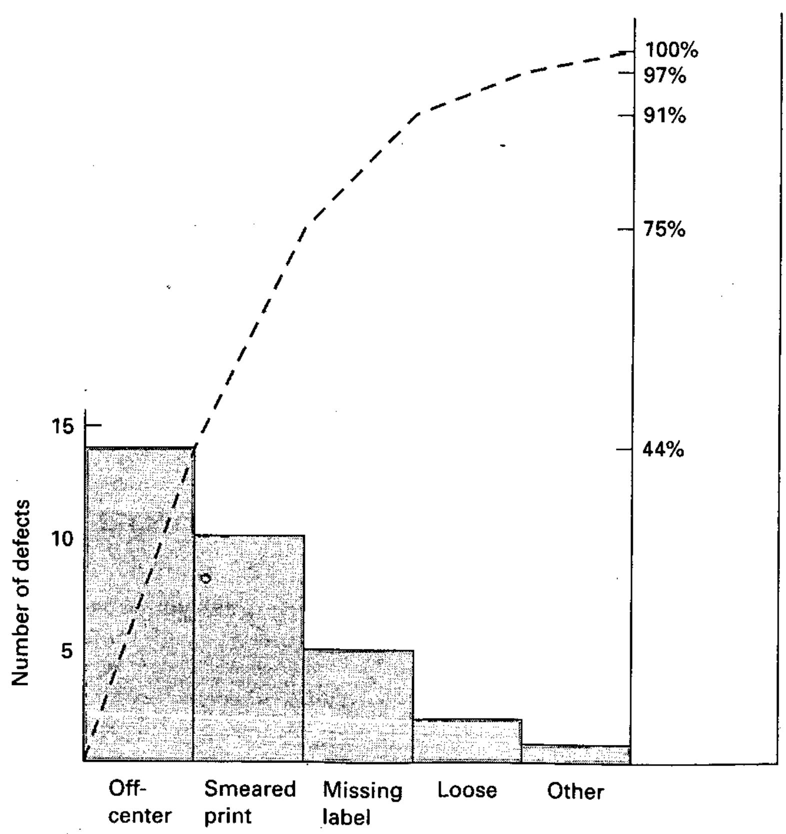


FIGURE 9.9

A Pareto diagram based on data in Figure 9.6



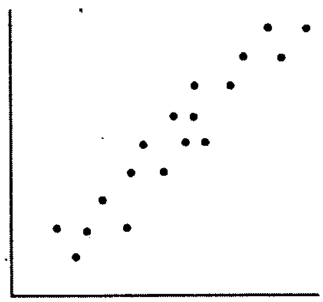


FIGURE 9.10

A scatter diagram

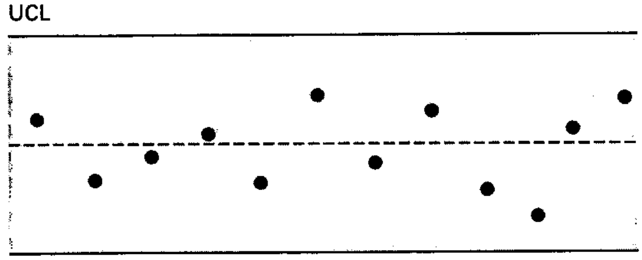


FIGURE 9.11

A control chart

humidity correspond to high numbers of errors, and vice versa. On the other hand, a *negative* (downward sloping) relationship would mean that when values of one variable are low, values of the other variable are high, and vice versa.

The higher the correlation between the two variables, the less scatter in the points; the points will tend to line up. Conversely, if there were little or no relationship between two variables, the points would be completely scattered. In Figure 9.10, the correlation between humidity and errors seems strong, because the points appear to scatter along an imaginary line.

Control Charts A **control chart** can be used to monitor a process to see if the process output is random. It can help detect the presence of *correctable* causes of variation. Figure 9.11 illustrates a control chart. Control charts also can indicate when a problem occurred and give insight into what caused the problem. Control charts are described in detail in Chapter 10.

control chart A statistical chart of time-ordered values of a sample statistic.

Cause-and-Effect Diagrams A **cause-and-effect diagram** offers a structured approach to the search for the possible cause(s) of a problem. It is also known as a **fishbone diagram** because of its shape, or an *Ishikawa diagram,* after the Japanese professor who developed the approach to aid workers overwhelmed by the number of possible sources of problems when problem solving. This tool helps to organize problem-solving efforts by identifying *categories* of factors that might be causing problems. Often this tool is used after brainstorming sessions to organize the ideas generated. Figure 9.12 illustrates one form of a cause-and-effect diagram.

cause-and-effect diagram Used to search for the cause(s) of a problem; also called *fishbone diagram.*

An example of an application of such a cause-and-effect diagram is shown in Figure 9.13. Each of the factors listed in the diagram is a potential source of ticket errors. Some are more likely causes than others, depending on the nature of the errors. If the cause is still not obvious at this point, additional investigation into the *root cause* may be necessary, involving a more in-depth analysis. Often, more detailed information can be obtained by asking *who, what, where, when, why,* and *how* questions about factors that appear to be the most likely sources of problems.

FIGURE 9.12

One format of a cause-and-effect diagram

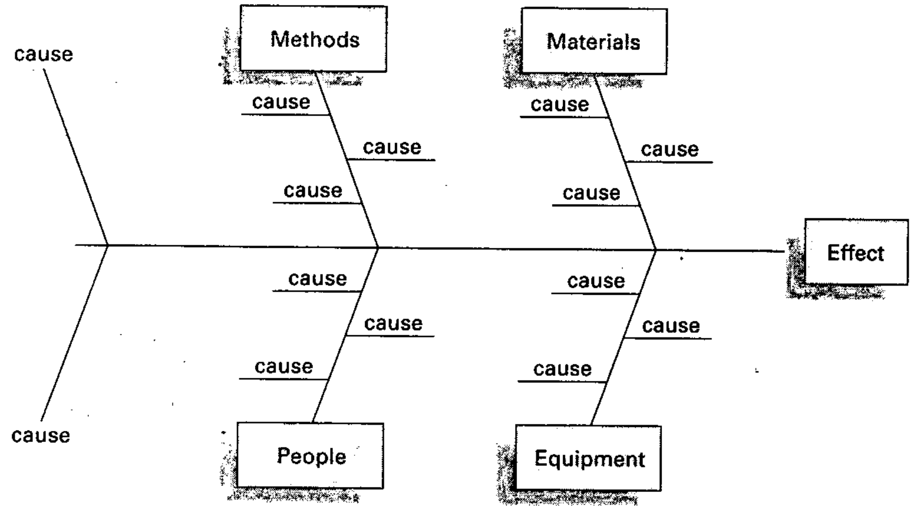
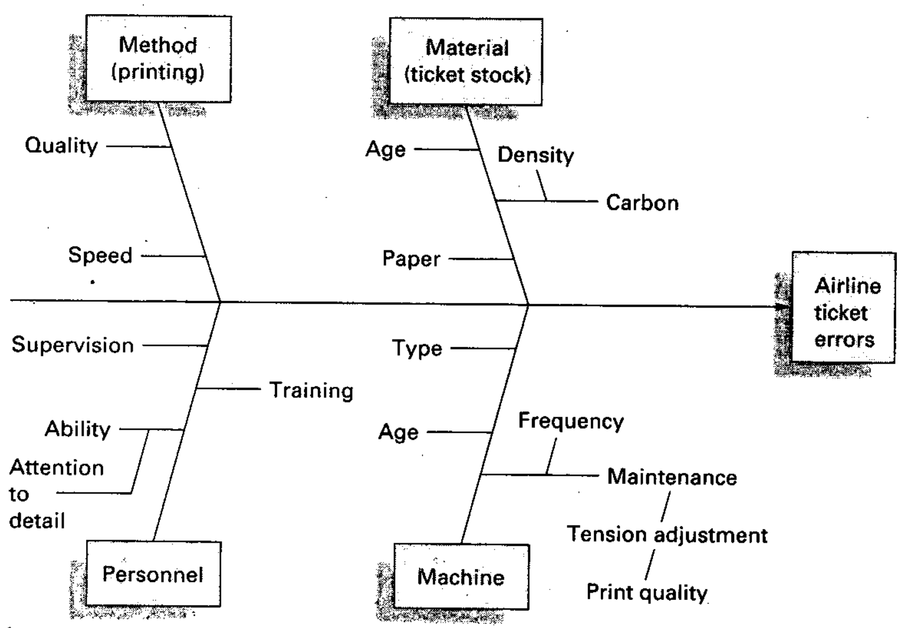


FIGURE 9.13

Cause-and-effect diagram for airline ticket errors

Source: Figure from Gitlow, et al, *Quality Management*, p. 313. Copyright © 1995 Richard D. Irwin. Reprinted by permission of McGraw-Hill Companies, Inc.



Continuous Improvement on the Free-Throw Line

READING

Timothy Clark and Andrew Clark

In 1924, Walter Shewhart developed a problem-solving method to continually improve quality by reducing variation (the difference between the ideal outcome and the actual situation). To help guide improvement efforts, Shewhart outlined a process referred to as the plan-do-study-act (PDSA) cycle. The PDSA cycle combined with the traditional concepts of decision making and problem solving are what my son and I used to continuously improve his basketball free-throw shooting.

Recognizing the Problem

Identify the Facts I had observed over a three-year period that in basketball games, my son Andrew's free-throw shooting percentage averaged between 45 percent and 50 percent.

Identify and Define the Process Andrew's process for shooting free throws was simple: Go to the free-throw line, bounce the ball four times, aim, and shoot.

(continued)

The desired outcome was a higher free-throw shooting percentage. An ideal outcome, or perfection, would be one in which 100 percent of the shots fall through the middle of the rim, land at the same spot on the floor every time, and roll straight back in the shooter's direction after landing.

Plot the Points To confirm my observations on the results of the current process, we went to the YMCA and Andrew shot five sets of 10 free throws for a total of 50 shots. His average was 42 percent. Results were recorded on a run chart (see Figure 1). I estimated the process was stable.

Decision Making

Identify the Causes Causes of variation in any process can be identified through the general categories of people, equipment, materials, methods, environment, and measurement. A cause-and-effect diagram is used to graphically illustrate the relationship between the effect—a low free-throw shooting percentage—and the principal causes (see Figure 2).

In analyzing my son's process, I noticed that he did not stand at the same place on the free-throw line every time. I believed his inconsistent shooting position affected the direction of the shot. If the shot goes left or right, there is a smaller probability that the ball will have a lucky bounce and go in. I also noticed that he didn't seem to have a consistent focal point.

Develop, Analyze, and Select Alternatives The alternatives selected for Andrew, a right-handed shooter, were for him to line up his right foot on the middle of the free-throw line, focus on the middle of the front part of the rim, and visualize the perfect shot before he released the ball. The modified process is:

1. Stand at the center of the free-throw line.
2. Bounce the ball four times.
3. Focus on the middle of the front part of the rim, and visualize a perfect shot.
4. Shoot.

Develop an Action Plan The course of action at this point was for Andrew to shoot five more sets of 10 free throws to test the effectiveness of the changes.

Problem Solving

Implement the Selected Alternative and Compare Actual with Expected Results The new process resulted in a 36 percent improvement in Andrew's average free-throw percentage at basketball practice, which raised his average to 57 percent (see Figure 3). The new process was first implemented in games toward the end of the 1994 season, and in the last three games, Andrew hit nine of his 13 free throws for a free-throw shooting average of 69 percent.

During the 1995 season, Andrew made 37 of his 52 free throws in games for an average of 71 percent. In one extremely close game where the other team was forced to foul Andrew's team in an effort to get the ball back, Andrew hit seven of his seven shots, which helped his team win the game. In team practices, the coaches had the players shoot two free throws and then rotate. For the entire season, Andrew hit 101 of 169 of his team practice free throws for an average of 60 percent.

As we monitored Andrew's process from March to Jan., we plotted the total number of practice shots made out of 50,

(continued)

FIGURE 1 Free-Throw Shooting Run Chart

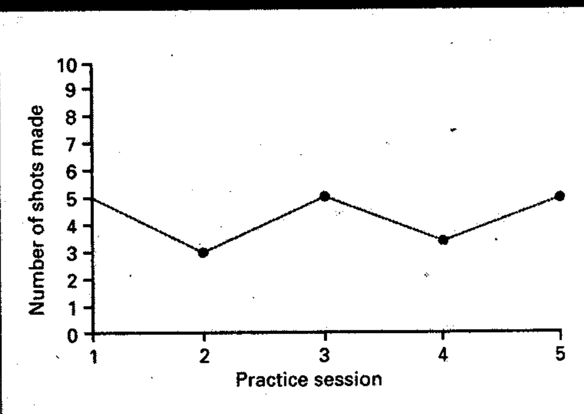


FIGURE 2 Free-Throw Shooting Cause-and-Effect Diagram

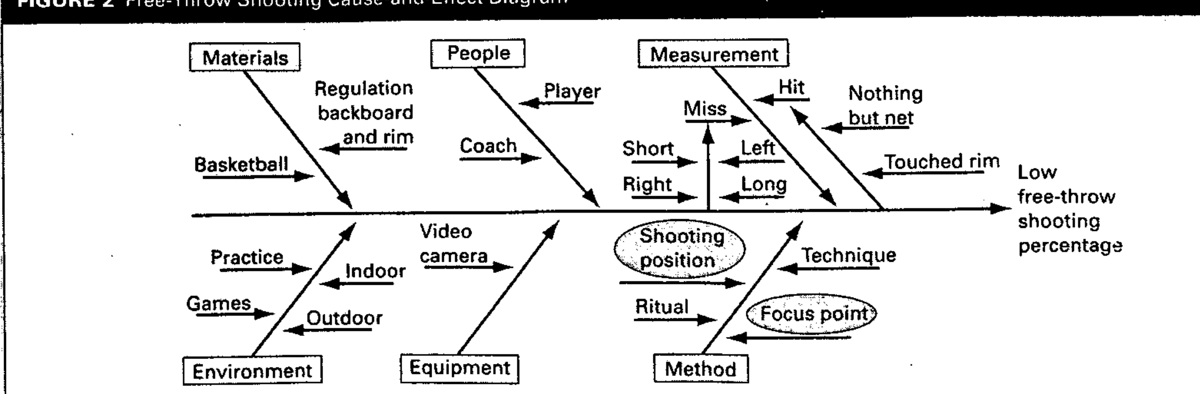


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FIGURE 3. Free-Throw Shots Made Before and After Implementing the PDSA Cycle

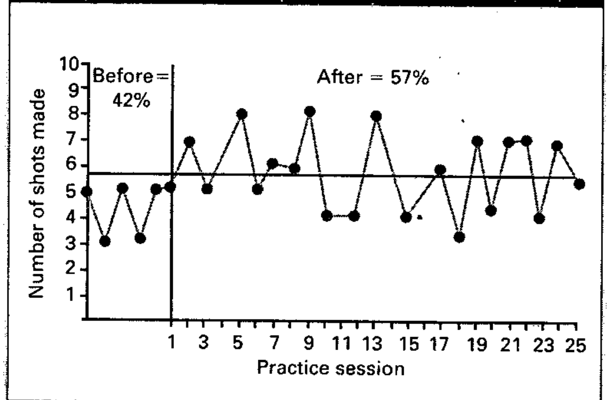
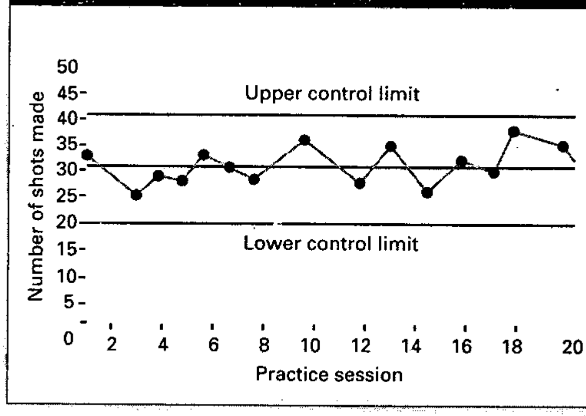


FIGURE 4 Determining Whether the Free-Throw Process Is Stable



using Shewhart's number-of-affected-units control chart (see Figure 4).

In the late summer of 1995, Andrew went to a basketball camp where he was advised to change his shooting technique, which reduced his shooting percentage during the 1996 season to 50 percent. We then reinstalled his old process, and his shooting percentage returned to its former level. In one series of 50 practice free throws, he hit 35 of 50 shots for an average of 70 percent and in another set, he hit an average of 64 percent. During the remaining team practices, Andrew hit 14 of 20 for an average of 70 percent.

During the 1996 and 1997 seasons, Andrew was a point guard and had fewer opportunities to shoot free throws, but he made nine of them for an average of 75 percent.

Overall Benefits In addition to the tangible results, such as improved free-throw shooting, the intangible benefits were also significant. For example, Andrew's confidence improved, and he learned how to determine when changes to his shooting technique resulted in improvement. W. Edwards Deming referred to this type of knowledge as profound.

Continuous Improvement

Take Appropriate Action Based on Study Results

In preparation for the 1998 season, Andrew's priorities for improvement are to continue to monitor his free-throw shooting to ensure it remains stable and to work on improving the shooting percentage of his two- and three-point shots.

Developing a knowledge and understanding of variation will change the way you look at the world forever and can lead to unprecedented levels of quality.

run chart Tool for tracking results over a period of time.

Run Charts A **run chart** can be used to track the values of a variable over time. This can aid in identifying trends or other patterns that may be occurring. Figure 9.14 provides an example of a run chart showing a decreasing trend in accident frequency over time. Important advantages of run charts are ease of construction and ease of interpretation.

Illustrations of the Use of Graphical Tools

This section presents some illustrations of the use of graphical tools in process or product improvement. Figure 9.15 begins with a check sheet that can be used to develop a Pareto chart of the types of errors found. That leads to a more focused Pareto diagram of the most frequently occurring type of error, followed (moving right) by a cause-and-effect diagram of the second most frequently occurring error. Additional cause-and-effect diagrams, such as errors by location, might also be used.

Figure 9.16 shows how Pareto charts measure the amount of improvement achieved in a before-and-after scenario of errors.

Figure 9.17 illustrates how control charts track two phases of improvement in a process that was initially out of control.

FIGURE 9.14

A run chart shows performance over time

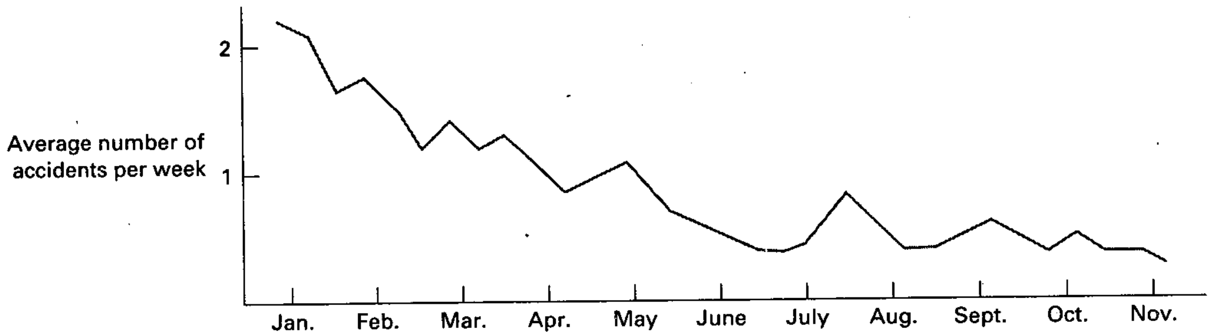


FIGURE 9.15

Employing graphical tools in problem solving

Check sheet: Type of error by location

<table>
<tr><th rowspan="2">Location</th><th colspan="5">Type of Error</th></tr>
<tr><th>C</th><th>B</th><th>D</th><th>A</th><th>E</th></tr>
<tr><td>1</td><td>||</td><td>|</td><td></td><td>|||</td><td>|</td></tr>
<tr><td>2</td><td>|</td><td>||</td><td>||</td><td>||</td><td></td></tr>
<tr><td>3</td><td>||</td><td>|||</td><td>|</td><td>||||</td><td></td></tr>
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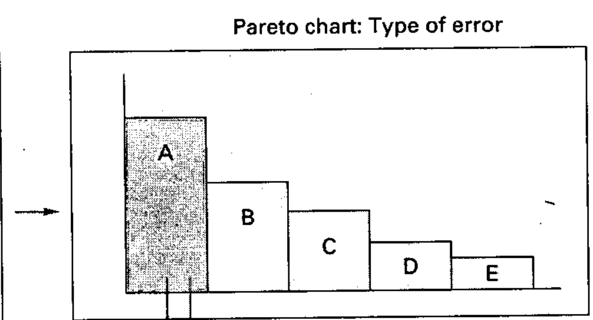
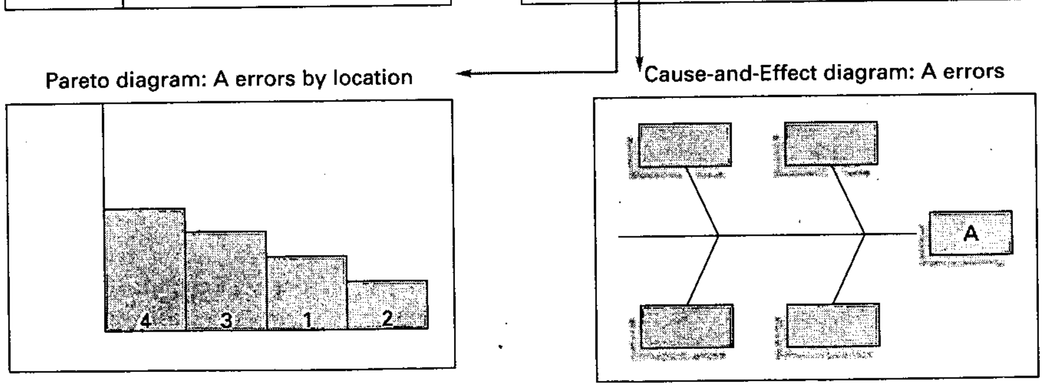




Methods for Generating Ideas

Some additional tools that are useful for problem solving and/or for process improvement are brainstorming, quality circles, interviewing, and benchmarking.

Brainstorming **Brainstorming** is a technique in which a group of people share thoughts and ideas on problems in a relaxed atmosphere that encourages unrestrained collective thinking. The goal is to generate a free flow of ideas on identifying problems, and finding causes, solutions, and ways to implement solutions. In successful brainstorming, criticism is absent, no single member is allowed to dominate sessions, and all ideas are welcomed. Structured brainstorming is an approach to assure that everyone participates.

brainstorming Technique for generating a free flow of ideas in a group of people.

FIGURE 9.16

Comparison of before and after using Pareto charts

IOM

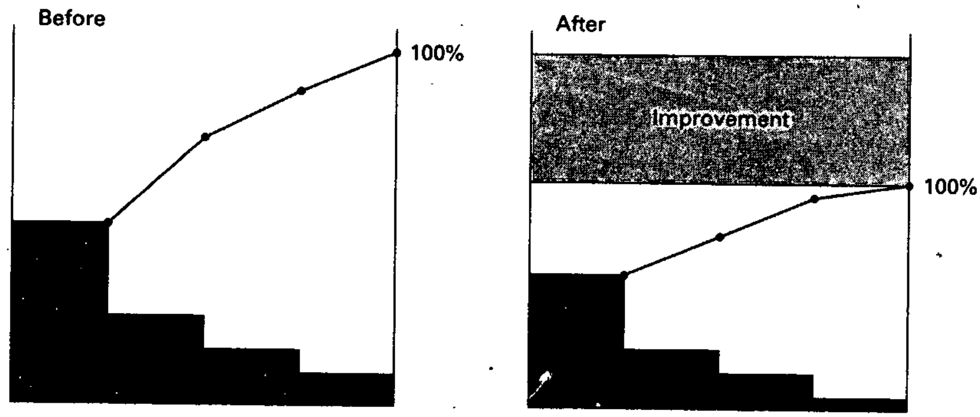
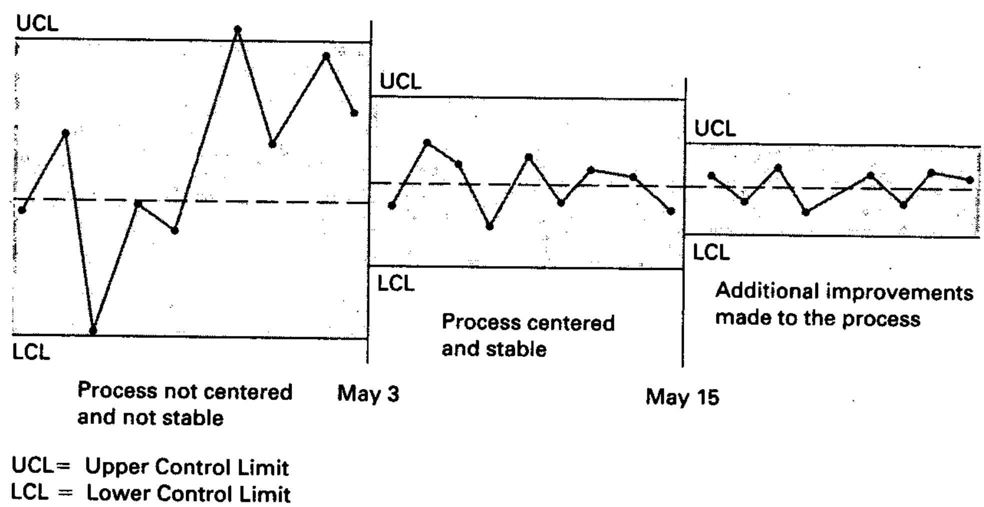


FIGURE 9.17

Using a control chart to track improvements



quality circles Groups of workers who meet to discuss ways of improving products or processes.

Quality Circles One way companies have tapped employees for ideas concerning quality improvement is through **quality circles.** The circles comprise a number of workers who get together periodically to discuss ways of improving products and processes. Not only are quality circles a valuable source of worker input, they also can motivate workers, if handled properly, by demonstrating management interest in worker ideas. Quality circles are usually less structured and more informal than teams involved in continuous improvement, but in some organizations quality circles have evolved into continuous improvement teams. Perhaps a major distinction between quality circles and teams is the amount of authority given to the teams. Typically, quality circles have had very little authority to implement any but minor changes; continuous improvement teams are sometimes given a great deal of authority. Consequently, continuous improvement teams have the added motivation generated by *empowerment.*

Either approach works best when it reaches decisions based on consensus. This may involve one or more of the following methods:

1. *List reduction* is applied to a list of possible problems or solutions. Its purpose is to clarify items and, in the *process,* reduce the list of items by posing questions about affordability, feasibility, and likelihood of solving the problem for each item.
2. A *balance sheet* approach lists the pros and cons of each item and focuses discussion on important issues.
3. *Paired comparisons* is a process by which each item on a list is compared with every other item, two at a time. For each pair, team members select the preferred item. This approach forces a choice between items. It works best when the list of items is small: say, five or fewer.

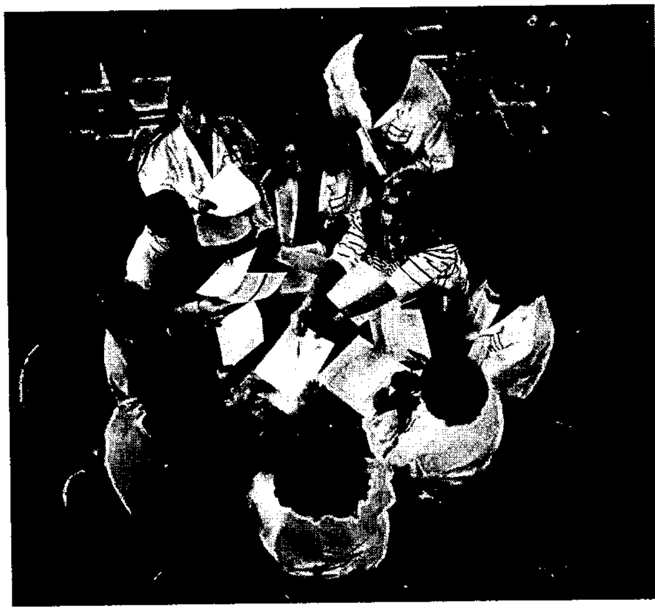
Interviewing Another technique a firm can use to identify problems or collect information about a problem is **interviewing.** Internal problems may require interviewing employees; external problems may require interviewing external customers.

interviewing Technique for identifying problems and collecting information.

Ideas for improvement can come from a number of sources: research and development, customers, competitors, and employees. Customer satisfaction is the ultimate goal of improvement activities, and customers can offer many valuable suggestions about products and the service process. However, they are unlikely to have suggestions for manufacturing processes.

Benchmarking **Benchmarking** is an approach that can inject new energy into improvement efforts. Summarized in Table 9.9, benchmarking is the process of measuring an organization's performance on a key customer requirement against the best in the industry, or against the best in any industry. Its purpose is to establish a standard against which performance is judged, and to identify a model for learning how to improve. A benchmark demonstrates the degree to which customers of other organizations are satisfied. Once a benchmark has been identified, the goal is to meet or exceed that standard through improvements in appropriate processes.

benchmarking Process of measuring performance against the best in the same or another industry.



At Solectron, a customer focus team plans for a customer's supply chain needs. Solectron's focus teams are composed of specialists from all areas of the organization, including manufacturing, engineering, materials, production control, and testing.

www.solectron.com

The benchmarking process usually involves these steps:

1. Identify a critical process that needs improvement (e.g., order entry, distribution, service after sale).
2. Identify an organization that excels in the process, preferably the best.
3. Contact the benchmark organization, visit it, and study the benchmark activity.
4. Analyze the data.
5. Improve the critical process at your own organization.

Selecting an industry leader provides insight into what competitors are doing; but competitors may be reluctant to share this information. Several organizations are responding to this difficulty by conducting benchmarking studies and providing that information to other organizations without revealing the sources of the data.

Selecting organizations that are world leaders in different industries is another alternative. For example, the Xerox Corporation uses many benchmarks: For employee involvement, Procter & Gamble; for quality process, Florida Power and Light and Toyota; for high-volume production, Kodak and Canon; for billing collection, American Express; for research and development, AT&T and Hewlett-Packard; for distribution, L.L. Bean and Hershey Foods; and for daily scheduling, Cummins Engine.

TABLE 9.9
The benchmarking approach

1. What organization does it the best?
2. How do they do it?
3. How do we do it now?
4. How can we change to match or exceed the best?

TABLE 9.10
The 5W2H approach

Category	5W2H	Typical Questions	Goal
Subject	What?	What is being done?	Identify the focus of analysis.
Purpose	Why?	Why is this necessary?	Eliminate unnecessary tasks.
Location	Where?	Where is it being done? Why is it done there? Would it be better to do it someplace else?	Improve the location.
Sequence	When?	When is it done? Would it be better to do it at another time?	Improve the sequence.
People	Who?	Who is doing it? Could someone else do it better?	Improve the sequence or output.
Method	How?	How is it being done? Is there a better way?	Simplify tasks, improve output.
Cost	How much?	How much does it cost now? What would the new cost be?	Select an improved method.

Source: Adapted from Alan Robinson, *Continuous Improvement in Operations: A Systematic Approach to Waste Reduction* (Cambridge, MA: Productivity Press, 1991), p. 246.

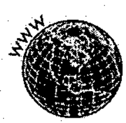
5W2H approach A method of asking questions about a process that includes what, why, where, when, who, how, and how much.

The 5W2H Approach Asking questions about the current process can lead to important insights about why the current process isn't working as well as it could, as well as potential ways to improve it. One method is called the **5W2H** (5 "w" words and 2 "h" words) approach (see Table 9.10).

Benchmarking Corporate Websites of Fortune 500 Companies

READING

www.dow.com



More and more people are using the Internet. And when these people want information about a company's products or services, they often go to the company's website. In a study of the home pages of Fortune 500 companies, 13 factors were deemed critical to quality. Those factors, and the survey results, are shown below:

1. Use of meta tags (e.g., keywords used by search engines) Yes, 70%; no, 30%
2. Meaningful home page title Yes, 97%; no, 3%
3. Unique domain name Yes, 91%; no, 9%
4. Search engine site registration 97% (average)
5. Server reliability 99% (average)
6. Average speed of loading (seconds) 28k, 19.3; 56k, 10.9; T1, 2.6 sec.
7. Average number of bad links .40
8. Average number of spelling errors .16
9. Visibility of contact information Yes, 74%; no, 26%
10. Indication of last update date Yes, 17%; no, 83%
11. A privacy policy Yes, 53%; no, 47%
12. Presence of a search engine Yes, 59%; no, 41%
13. Translation to multiple languages Yes, 11%; no, 89%

The corporations are doing well on most factors, but they need improvement on the last five.

The list is a handy reference other organizations can use to benchmark their existing home pages to see where improvements are needed or to develop effective home pages.

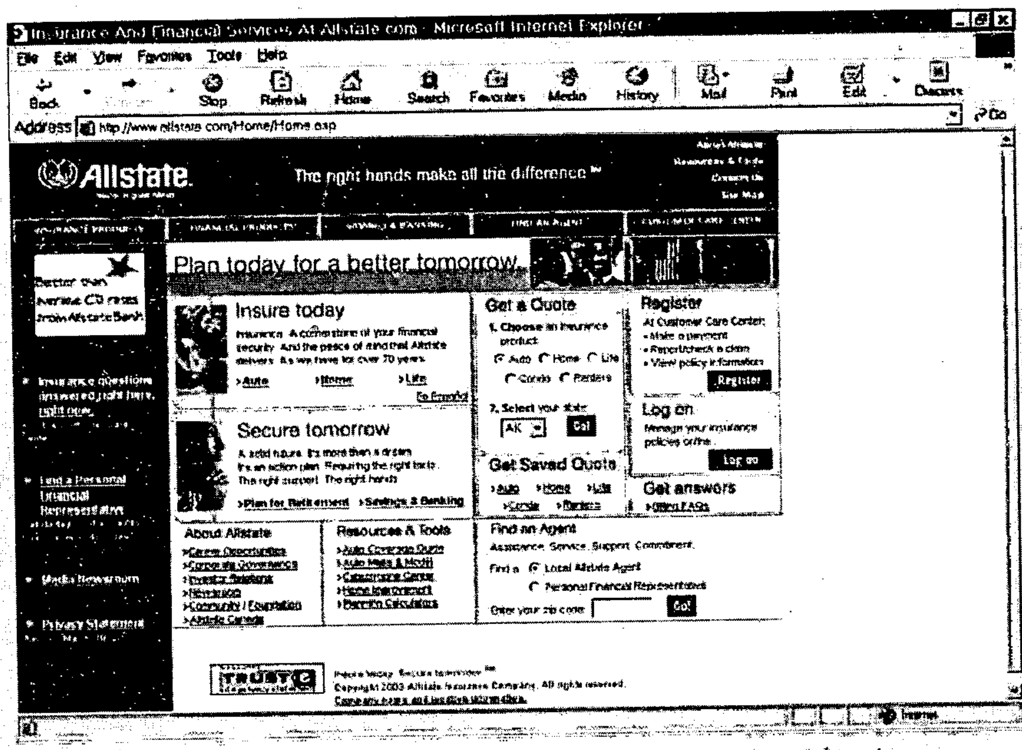
Question

Give one reason for the importance of each factor.

Source: Based on Nabil Tamimi, Murli Rajan, and Rose Sebastianelli, "Benchmarking the Home Pages of 'Fortune 500' Companies," *Quality Progress*, July 2000, pp. 47–51.

(continued)

(concluded)



www.allstate.com

Allstate Insurance Company's home page makes product information, quotes, and service transactions easy and efficient.

Operations Strategy

In order for total quality management to be successful, it is essential that a majority of those in an organization "buy in" to the idea. Otherwise, there is a risk that a significant portion of the benefits of the approach will not be realized. Therefore, it is important to give this sufficient attention, and to confirm that concordance exists before plunging ahead. A key aspect of this is a "top-down" approach: Top management needs to be visibly involved and needs to be supportive, both financially and emotionally. Also important is education of managers and workers in the concepts, tools, and procedures of quality. Again, if education is incomplete, there is the risk that TQM will not produce the desired benefits.

It is not enough for an organization to incorporate quality into its operations; the entire supply chain has to be involved. Problems such as defects in purchased parts, long lead times, and late or missed deliveries of goods or services all negatively impact an organization's ability to satisfy its customers. So it is essential to incorporate quality throughout the supply chain.

SUMMARY

The success of foreign companies in North American markets revealed them as formidable competitors. They built reputations for quality products. Moreover, they achieved their success using management techniques quite different from those traditionally practiced in the United States. This caused American managers to reexamine their own approaches and to adopt some of those different approaches in order to improve quality and become more competitive.

Quality is defined according to various dimensions that pertain to customer satisfaction. The consequences of poor quality include loss of market share, liability claims, a decrease in productivity, and an increase in costs. Quality costs include costs related to prevention, appraisal, and failure. Determinants of quality are design, conformance to design, ease of use, and service after delivery.

Modern quality management is directed at preventing mistakes rather than finding them after they occur and reducing process output variation. Currently, the business community shows widespread interest in improving quality and competitiveness.

The chapter includes a description of the key contributors to quality management, and it outlines the ISO 9000 and ISO 14000 international quality standards.

Three awards of distinction, the Baldrige Award, the European Quality Award, and the Deming Prize, are given annually to organizations that have shown great achievement in quality management.

Total quality management is a never-ending pursuit of quality that involves everyone in an organization. The driving force is customer satisfaction; a key philosophy is continuous improvement. Training of managers and workers in quality concepts, tools, and procedures is an important aspect of the approach. Teams are an integral part of TQM.

Two major aspects of the TQM approach are problem solving and process improvement. Six-sigma programs are a form of TQM. They emphasize the use of statistical and management science tools on selected projects to achieve business results.

KEY TERMS

appraisal costs, 391
Baldrige Award, 393
benchmarking, 417
brainstorming, 415
cause-and-effect (fishbone) diagram, 411
check sheet, 407
continuous improvement, 398
control chart, 411
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total quality management (TQM), 398

SOLVED PROBLEM

Problem

The county sheriff's department handed out the following tickets on a summer weekend. Make a check sheet and a Pareto diagram for the types of infraction.

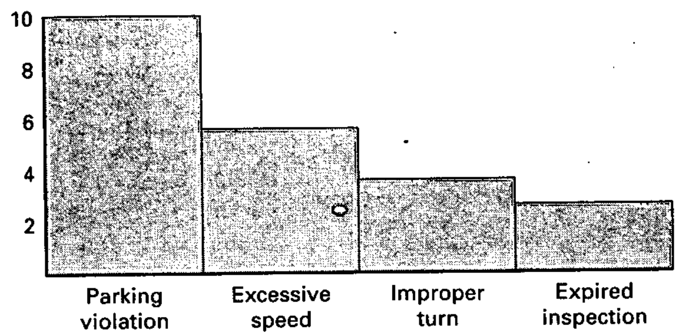
Ticket Number	Infraction	Ticket Number	Infraction
1	Excessive speed	11	Expired inspection
2	Expired inspection	12	Parking violation
3	Improper turn	13	Improper turn
4	Excessive speed	14	Parking violation
5	Parking violation	15	Excessive speed
6	Parking violation	16	Parking violation
7	Excessive speed	17	Parking violation
8	Parking violation	18	Parking violation
9	Improper turn	19	Excessive speed
10	Parking violation	20	Parking violation

Solution

Check sheet (list the types of infractions, tally, summarize frequencies):

Infraction	Tally	Frequency
Excessive speed	~~////~~	5
Expired inspection	//	2
Improper turn	///	3
Parking violation	~~////~~ ~~////~~	10

Pareto diagram (array infractions from highest frequency to lowest):



DISCUSSION AND REVIEW QUESTIONS

1. List and briefly explain the dimensions of quality.
2. Explain the terms *quality of design* and *quality of conformance.*
3. What are some possible consequences of poor quality?
4. Use the dimensions of quality to describe typical characteristics of these products and services:
   a. A television set
   b. A restaurant meal (product)
   c. A restaurant meal (service)
   d. Painting a house
5. List the determinants of quality.
6. Describe the quality–ethics connection.
7. Select one of the quality gurus and briefly describe his major contributions to quality management.
8. What is ISO 9000, and why is it important for global businesses to have ISO 9000 certification?
9. Briefly explain how a company can achieve lower production costs by improving the quality of its products or services.
10. What are the key elements of the TQM approach? What is the driving force behind TQM?
11. Briefly describe each of the seven quality tools.
12. Briefly define or explain each of these tools:
    a. Brainstorming
    b. Benchmarking
    c. Run charts
13. Explain each of these methods:
    a. The plan-do-study-act cycle
    b. The 5W2H approach
14. List the steps of problem solving.
15. Select four tools and describe how they could be used in problem solving.
16. List the steps of process improvement.
17. Select four tools and describe how they could be used for process improvement.

TAKING STOCK

1. What trade-offs are involved in deciding on how much to spend on quality improvement?
2. Who needs to be involved in setting priorities for quality improvement?
3. Name several ways that technology has had an impact on quality.

CRITICAL THINKING EXERCISE

A computer repair shop had received a number of complaints on the length of time it took to make repairs. The manager responded by increasing the repair staff by 10 percent. Complaints on repair time quickly decreased, but then complaints on the cost of repairs suddenly increased. Oddly enough, when repair costs were analyzed, the manager found that the average cost of repair had actually decreased relative to what it was before the increase in staff. What are some possible explanations for the complaints, and what actions might the manager contemplate?

PROBLEMS

1. Make a check sheet and then a Pareto diagram for the following car repair shop data.

Ticket No.	Work	Ticket No.	Work
1	Tires	16	Tires
2	Lube & oil	17	Lube & oil
3	Tires	18	Brakes
4	Battery	19	Tires
5	Lube & oil	20	Brakes
6	Lube & oil	21	Lube & oil
7	Lube & oil	22	Brakes
8	Brakes	23	Transmission
9	Lube & oil	24	Brakes
10	Tires	25	Lube & oil
11	Brakes	26	Battery
12	Lube & oil	27	Lube & oil
13	Battery	28	Battery
14	Lube & oil	29	Brakes
15	Lube & oil	30	Tires

2. An air-conditioning repair department manager has compiled data on the primary reason for 41 service calls for the previous week, as shown in the table. Using the data, make a check sheet for the problem types for each customer type, and then construct a Pareto diagram for each type of customer.

Job Number	Problem/ Customer Type	Job Number	Problem/ Customer Type	Job Number	Problem/ Customer Type
301	F/R	315	F/C	329	O/C
302	O/R	316	O/C	330	N/R
303	N/C	317	W/C	331	N/R
304	N/R	318	N/R	332	W/R
305	W/C	319	O/C	333	O/R
306	N/R	320	F/R	334	O/C
307	F/R	321	F/R	335	N/R
308	N/C	322	O/R	336	W/R
309	W/R	323	F/R	337	O/C
310	N/R	324	N/C	338	O/R
311	N/R	325	F/R	339	F/R
312	F/C	326	O/R	340	N/R
313	N/R	327	W/C	341	O/C
314	W/C	328	O/C		

Key: Problem type:
N = Noisy
F = Equipment failure
W = Runs warm
O = Odor

Customer type:
C = Commercial customer
R = Residential customer

3. Prepare a run chart similar to Figure 9.14 for the occurrences of defective computer monitors based on the following data, which an analyst obtained from the process for making the monitors. Workers are given a 15-minute break at 10:15 A.M. and 3:15 P.M., and a lunch break at noon. What can you conclude?

Interval Start Time	Number of Defects	Interval Start Time	Number of Defects
8:00	1	9:00	0
8:15	0	9:15	1
8:30	0	9:30	1
8:45	1	9:45	2

10:00	3	2:00	1
10:30	1	2:15	0
10:45	0	2:30	2
11:00	0	2:45	2
11:15	0	3:00	3
11:30	1	3:30	0
11:45	3	3:45	1
1:00	1	4:00	0
1:15	0	4:15	0
1:30	0	4:30	1
1:45	1	4:45	3

4. Prepare a run diagram for this emergency call data. Use five-minute intervals (i.e., count the calls received in each five-minute interval. Use intervals of 0–4, 5–9, etc.). Note: Two or more calls may occur in the same minute; there were three operators on duty this night. What can you conclude from the run chart?

Call	Time	Call	Time
1	1:03	22	1:56
2	1:06	23	1:56
3	1:09	24	2:00
4	1:11	25	2:00
5	1:12	26	2:01
6	1:17	27	2:02
7	1:21	28	2:03
8	1:27	29	2:03
9	1:28	30	2:04
10	1:29	31	2:06
11	1:31	32	2:07
12	1:36	33	2:08
13	1:39	34	2:08
14	1:42	35	2:11
15	1:43	36	2:12
16	1:44	37	2:12
17	1:47	38	2:13
18	1:48	39	2:14
19	1:50	40	2:14
20	1:52	41	2:16
21	1:53	42	2:19

5. Suppose that a table lamp fails to light when turned on. Prepare a simple cause-and-effect diagram to analyze possible causes.
6. Prepare a cause-and-effect diagram to analyze the possible causes of late delivery of parts ordered from a supplier.
7. Prepare a cause-and-effect diagram to analyze why a machine has produced a large run of defective parts.
8. Prepare a scatter diagram for each of these data sets and then express in words the apparent relationship between the two variables. Put the first variable on the horizontal axis and the second variable on the vertical axis.

a.

Age	24	30	22	25	33	27	36	58	37	47	54	28	42	55
Absenteeism rate	6	5	7	6	4	5	4	1	3	2	2	5	3	1

b.

Temperature (F)	65	63	72	66	82	58	75	86	77	65	79
Error rate	1	2	0	0	3	3	1	5	2	1	3

9. Prepare a flowchart that describes going to the library to study for an exam. Your flowchart should include these items: finding a place at the library to study, checking to see if you have your book, paper, highlighter, and so forth; traveling to the library, and the possibility of moving to another location if the place you chose to study starts to get crowded.
10. College students trying to register for a course sometimes find that the course has been closed, or the section they want has been closed. Prepare a cause-and-effect diagram for this problem.
11. The county sheriff's department responded to an unusually large number of vehicular accidents along a quarter-mile stretch of highway in recent months. Prepare a cause-and-effect diagram for this problem.
12. Suppose you are going to have a prescription filled at a local pharmacy. Referring to the dimensions of service quality, for each dimension, give an example of how you would judge the quality of the service.

Chick-n-Gravy Dinner Line

CASE

The operations manager of a firm that produces frozen dinners had received numerous complaints from supermarkets about the firm's Chick-n-Gravy dinners. The manager then asked her assistant, Ann, to investigate the matter and to report her recommendations.

Ann's first task was to determine what problems were generating the complaints. The majority of complaints centered on five defects: underfilled packages, a missing item, spills/mixed items, unacceptable taste, and improperly sealed packages.

Next, she took samples of dinners from the two production lines and examined each sample, making note of any defects that she found. A summary of those results is shown in the table.

The data resulted from inspecting approximately 800 frozen dinners. What should Ann recommend to the manager?

			DEFECT OBSERVED				
Date	**Time**	**Line**	**Underfilled**	**Missing Item**	**Spill/ Mixed**	**Unacceptable Taste**	**Improperly Sealed**
5/12	0900	1		√√	√	√√√	
5/12	1330	2			√√		√√
5/13	1000	2				√	√√√
5/13	1345	1	√√		√√		
5/13	1530	2		√√	√√√		√
5/14	0830	1		√√√		√√√	
5/14	1100	2	√		√	√√	
5/14	1400	1			√		√
5/15	1030	1		√√√		√√√√√	
5/15	1145	2			√	√√	
5/15	1500	1	√		√		
5/16	0845	2				√√	√√
5/16	1030	1		√√√	√	√√√	
5/16	1400	1					
5/16	1545	2	√	√√√√√	√	√	√√

Tip Top Markets

CASE

Tip Top Markets is a regional chain of supermarkets located in the Southeastern United States. Karen Martin, manager of one of the stores, was disturbed by the large number of complaints from customers at her store, particularly on Tuesdays, so she obtained complaint records from the store's customer service desk for the last eight Tuesdays.

(continued)

Assume you have been asked to help analyze the data and to make recommendations for improvement. Analyze the data using a check sheet, a Pareto diagram, and run charts. Then construct a cause-and-effect diagram for the leading category on your Pareto diagram.

On July 15, changes were implemented to reduce out-of-stock complaints, improve store maintenance, and reduce checkout lines/pricing problems. Do the results of the last two weeks reflect improvement?

Based on your analysis, prepare a list of recommendations that will address customer complaints.

June 1

- out of orange yogurt
- bread stale
- checkout lines too long
- overcharged
- double charged
- meat smelled strange
- charged for item not purchased
- couldn't find the sponges
- meat tasted strange
- store too cold
- light out in parking lot
- produce not fresh
- lemon yogurt past sell date
- couldn't find rice
- milk past sell date
- stock clerk rude
- cashier not friendly
- out of maple walnut ice cream
- something green in meat
- didn't like music
- checkout lines too slow

June 8

- fish smelled funny
- out of diet bread
- dented can
- out of hamburger rolls
- fish not fresh
- cashier not helpful
- meat tasted bad
- ATM ate card
- slippery floor
- music too loud
- undercharged
- out of roses
- meat spoiled
- overcharged on two items
- store too warm
- out of ice
- telephone out of order
- overcharged
- rolls stale
- bread past sale date

June 15

- wanted smaller size
- too cold in store
- out of Wheaties
- out of Minute Rice
- cashier rude
- fish tasted fishy
- ice cream thawed
- double charged on hard rolls
- long wait at checkout
- wrong price on item
- overcharged
- fish didn't smell right
- overcharged on special
- couldn't find aspirin
- undercharged
- checkout lines too long
- out of diet cola
- meat smelled bad
- overcharged on eggs
- bread not fresh
- didn't like music
- lost wallet
- overcharged on bread

June 22

- milk past sales date
- store too warm
- foreign object in meat
- store too cold
- eggs cracked
- couldn't find lard
- out of 42 oz. Tide
- fish really bad
- windows dirty
- couldn't find oatmeal
- out of Bounty paper towels
- overcharged on orange juice
- lines too long at checkout
- couldn't find shoelaces
- out of Smucker's strawberry jam
- out of Frosty Flakes cereal
- out of Thomas' English Muffins

June 29

- checkout line too long
- out of Dove soap
- out of Bisquick
- eggs cracked
- store not clean
- store too cold
- cashier too slow
- out of skim milk
- charged wrong price
- restroom not clean
- couldn't find sponges
- checkout lines slow
- out of 18 oz. Tide
- out of Campbell's turkey soup
- out of pepperoni sticks
- checkout lines too long
- meat not fresh
- overcharged on melon

July 6

- out of straws
- out of bird food
- overcharged on butter
- out of masking tape
- stockboy was helpful
- lost child
- meat looked bad
- overcharged on butter
- out of Swiss chard
- too many people in store
- out of bubble bath
- out of Dial soap
- store too warm
- price not as advertised
- need to open more checkouts
- shopping carts hard to steer
- debris in aisles
- out of Drano
- out of Chinese cabbage
- store too warm
- floors dirty and sticky
- out of Diamond chopped walnuts

(continued)

(concluded)

July 13

- wrong price on spaghetti
- water on floor
- store looked messy
- store too warm
- checkout lines too long
- cashier not friendly
- out of Cheese Doodles
- triple charged
- out of Saran Wrap
- out of Dove Bars
- undercharged
- out of brown rice
- out of mushrooms
- overcharged
- checkout wait too long
- shopping cart broken
- couldn't find aspirin
- out of Tip Top lunch bags
- out of Tip Top straws

July 20

- out of cucumbers
- checkout lines too slow
- found keys in parking lot
- lost keys
- wrong price on sale item
- overcharged on corn
- wrong price on baby food
- out of 18 oz. Tide
- out of Tip Top tissues
- checkout lines too long
- out of romaine lettuce
- out of Tip Top toilet paper
- out of red peppers
- out of Tip Top napkins
- out of apricots
- telephone out of order
- out of cocktail sauce
- water on floor
- out of onions
- out of squash
- out of iceberg lettuce
- out of Tip Top paper towels

July 27

- out of bananas
- reported accident in parking lot
- wrong price on cranapple juice
- out of carrots
- out of fresh figs
- out of Tip Top napkins
- out of Tip Top straws
- windows dirty
- out of iceberg lettuce
- dislike store decorations
- out of Tip Top lunch bags
- out of vanilla soy milk
- wanted to know who won the lottery
- store too warm
- oatmeal spilled in bulk section
- telephone out of order
- out of Tip Top tissues
- water on floor
- out of Tip Top paper towels
- out of Tip Top toilet paper
- spaghetti sauce on floor
- out of Peter Pan crunchy peanut butter

Aesop on Quality Systems

READING

Denise E. Robitaille

Aesop, a fabulist who lived in the sixth century B.C., traveled through Greece and the Mediterranean area as an instructor, philosopher, and diplomat. His advice was sought on matters of state. Through his fables, he created an amusing vehicle for illustrating the foibles of human beings. Filled with object lessons that survive into our time, his tales provide insight into the breakdowns and pitfalls 20th century businesses contend with every day.

What can Aesop's fable about the goat and the goatherd teach us about quality auditing?

Imagine that the master of a medium-sized goat farm is preparing for a third-party audit to be conducted on behalf of a local dairy that wishes to purchase some of his goats. He takes great care with his goats, knowing well-tended animals produce the best milk. He is also proud that his beautiful goats have won numerous prizes at town fairs.

Two days before the audit, the master's goatherd, whose evening task is to gather all the goats and return them to their pen for the night, has trouble with one recalcitrant goat, which refuses to budge. The goatherd, after much fruitless cajoling, throws several stones at the goat to frighten her into the pen. In the process, he breaks one of her horns. The goatherd begs the goat not to tell the master. The goat replies, "I may be silent. But the broken horn will speak for itself."

When the auditor arrives, the master regales him with numerous examples of how well his goats are treated. The auditor proceeds to assess the herd and finds the goat with the broken horn. Despite all he has been told, the auditor is required to report that although the master has insisted the animals are well treated, the objective evidence is a goat with a broken horn. The data clearly indicate inconsistencies between this vendor's procedures and the actual practice.

(continued)

The client, an avid proponent of ISO 9000, concludes through his vendor assessment process that the goatherd will have to implement corrective action and provide verification before he can be qualified to sell the dairy any goats.

The Ant and the Grasshopper

A Grasshopper happened upon an Ant who was toiling in preparation for the long winter ahead. She asked of the Ant, "Why do you work so hard on such a pleasant day? Why not dance and sing as I do?" The Ant responded, "I need to plan and prepare myself for the cold weather to come." The Grasshopper laughed and danced away. When the first snows fell the Grasshopper perished. The Ant, snug and secure in her well-provisioned nest, survived and, indeed, prospered oblivious to the tempest outside her home.

Many years ago, Aesop identified the value of good planning and the dire consequences of failing to do so. Today, that value is articulated in the second clause of the ISO 9000 standard. The first clause of the ISO 9000 standard specifically addresses the need to make available necessary resources to ensure the fulfillment of the quality objectives. And we have found that planning is the first step of W. Edwards Deming's plan-do-study-act cycle. Careful planning is an indisputable key element of any quality system.

The Wild Boar and the Fox

A Fox observed a Wild Boar sharpening his tusks. There appearing to be no imminent danger, so the Fox asked, "Why do you sharpen your teeth when your enemies are not around?" The Wild Boar responded, "I would have no time to sharpen them if my enemies were upon me."

Aesop gives us a powerful case for the ninth clause of the ISO 9000 standard, which clearly mandates equipment be maintained so it is reliable when needed. How many of us have missed an important ship date because a vital piece of equipment failed at a critical period due to lack of maintenance?

The Farmer and the Stork

A Farmer cast a net upon his fields in an attempt to capture the cranes that had been eating his seed. In with the cranes, he snared a Stork. The Stork pleaded for his life, saying, "Honorable Farmer, I am not like these others who came to steal your seed. I am a Stork." The Farmer replied, "You may very well be a stork, but from the evidence here, I can only assume that you, too, have come to eat my seeds." And with that he slew the Stork along with the cranes.

The ISO 10011 standard addresses the guidelines for auditing a quality system. An auditor's role is to report findings objectively. Documentation and records should be accurate and reflect actual practices. Evidence that contradicts the auditee will result in an auditor finding inconsistencies between procedures and practices.

Belling the Cat

Once there were a colony of mice inhabiting a large house. The mice were constantly attacked by a cunning and overzealous Cat. The mice held a council in which they discussed how to solve their problem. A clever young mouse rose and offered the following solution: "If we could hear the Cat coming, we would be able to flee in time. Therefore, I propose that we hang a bell around the Cat's neck." The mice cheered wildly over the brilliant solution until an aged mouse stepped to the podium. The elder mouse spoke. "I have only one question. Who shall bell the Cat?"

Returning to Deming's cycle and to any plans for corrective/preventive action, it is wisest to consider the stakeholders and the organization's capability to implement a plan. Many plans fail due to this failure to assess human resources and adequately address constraints. It is always easiest to come up with a plan when someone else is accountable for its implementation.

The Ass and the Mule

An Ass and a Mule were both heavily laden with wares for the monthly fair. The Ass, being smaller and less agile on steep slopes, asked the Mule to relieve him of his burden. The Mule ignored his pleas. Shortly thereafter, the Ass collapsed under his burden and died. The master skinned the dead animal and then placed both his load and the Ass's hide on the Mule's back. The Mule was obliged to carry not only his load, but that of his dead companion.

Imagine the ass is an overburdened department. The mule represents management. Failing to recognize that the department is over-taxed and in need of assistance, management actually contributes to the collapse of an essential process and is left with the need to assume the consequences of that breakdown. Had management fulfilled the mandate to provide adequate resources, the breakdown would have been avoided.

The Pig, the Sheep, and the Goat

The Pig, the Sheep, and the Goat were all penned in for the night. The Pig whined of his condition. The Sheep and the Goat, wearied by his constant complaining, finally said, "We are in the same pen with you. Yet you do not hear us whining." The Pig answered, "The master takes from you only your wool and your milk. It is a different matter with me."

This fable reiterates the need for management's involvement in the implementation of a quality system. If managers attempt to detach themselves from accountability for the achievement of a goal, they may very well find that their staff assigns to itself the role of the pig and identifies executive managers as the sheep and goats. The fable also serves as an object lesson for Deming's tenet: "Drive out fear."

The Dying Father and His Sons

A Father on his death bed told his Sons that there was a great treasure to be found in his vineyard. After he had died the Sons

(continued)

(concluded)

raced out into the fields and overturned all the soil in search of the prize. No treasure was found, but, due to the revitalization of the soil, the vineyard yielded a bountiful harvest.

Many companies pursue registration to ISO 9000 or another quality standard under pressure from their customers or as a marketing strategy. Along the way to implementation, they discover they have so improved their procedures and processes that the benefits exceed all their expectations, and their company prospers.

The Boy Bathing and the Traveler

A Traveler happened upon a drowning Boy who had foolishly chosen to bathe in a river with a swift current. The Traveler chastised the Boy for his imprudence and then left him to drown. As he sank beneath the water the Boy thought, "How worthless it is to offer criticism without aid."

None of us would leave a drowning victim to perish. We might, however, leave a process owner to tread water by failing to provide problem-solving skills or necessary resources. Consider the unproductive nature of a quality system that does not seamlessly integrate the audit function, corrective action, and the mandate for management to provide necessary resources. In such an instance, management only looks at a list of nonconformances and does not provide a vehicle for root-cause analysis or direction for corrective action. The auditee is left without the adequate resources to properly address his problem.

A further lesson that may be derived from all of Aesop's fables is a reminder that quality systems should reflect common sense. ISO 9000 or any quality standard should only exist as a framework that facilitates the fulfillment of the quality objectives. But, the fundamentals are not new. Good planning, accountability, objective evidence, and maintenance are concepts with validity that have long survived the test of time. Indeed, as has been illustrated, they have been around for over two millennia.

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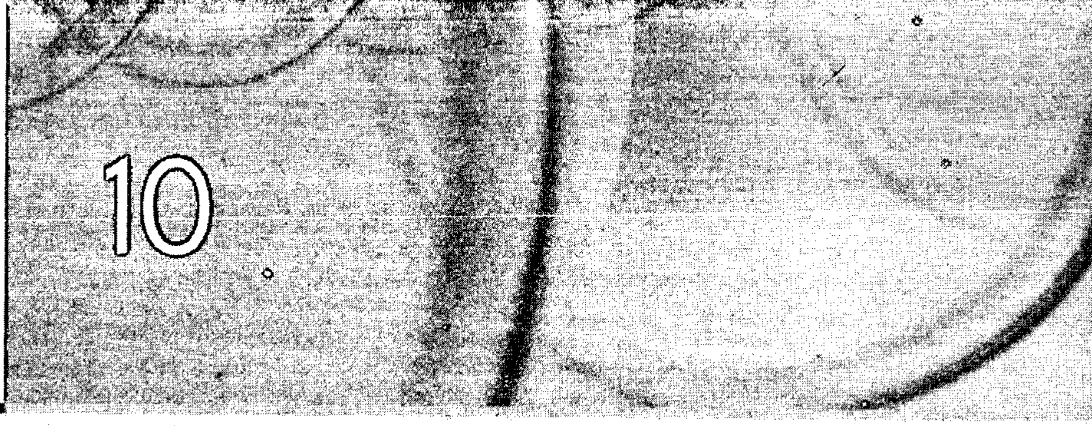
CHAPTER 10



Quality Control

LEARNING OBJECTIVES

After completing this chapter, you should be able to:

1. List and briefly explain the elements of the control process.
2. Explain how control charts are used to monitor a process, and the concepts that underlie their use.
3. Use and interpret control charts.
4. Use run tests to check for nonrandomness in process output.
5. Assess process capability.

CHAPTER OUTLINE

This chapter covers quality control. The purpose of quality control is to assure that processes are performing in an acceptable manner. Companies accomplish this by monitoring process output using statistical techniques. **Quality control** is a process that measures output relative to a standard, and acts when output does not meet standards. If the results are acceptable, no further action is required; unacceptable results call for corrective action.

quality control A process that evaluates output relative to a standard, and takes corrective action when output doesn't meet standards.

INTRODUCTION

Quality assurance that relies primarily on inspection of previously produced items is referred to as *acceptance sampling.* It is described in the chapter supplement. Quality control efforts that occur during production are referred to as *statistical process control,* and these we examine in the following sections.

The best companies emphasize *designing quality into the process,* thereby greatly reducing the need for inspection or control efforts. As you might expect, different business organizations are in different stages of this evolutionary process: The least progressive rely heavily on inspection. Many occupy a middle ground that involves some inspection and a great deal of process control. The most progressive have achieved an inherent level of quality that is sufficiently high that they can avoid wholesale inspection activities and process control activities by mistake prevention. That is the ultimate goal. Figure 10.1 illustrates these phases of quality assurance.

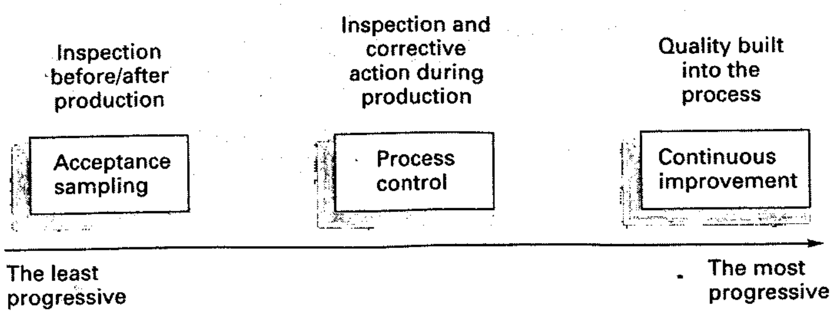


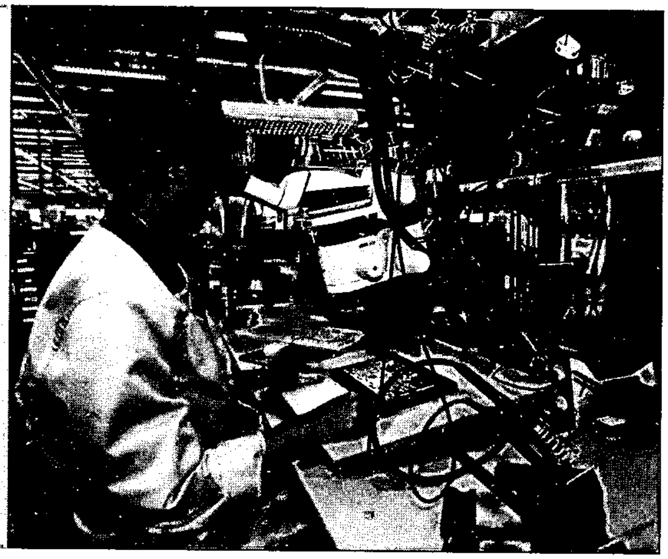
FIGURE 10.1

Approaches to quality assurance

INSPECTION

inspection Appraisal of goods or services.

Inspection is an appraisal activity that compares goods or services to a standard. Inspection can occur at three points: before production, during production, and after production. The logic of checking conformance before production is to make sure that inputs are acceptable. The logic of checking conformance during production is to make sure that the conversion of inputs into outputs is proceeding in an acceptable manner. The logic of checking conformance of output is to make a final verification of conformance before passing goods on to customers.



At the Ericsson mobile phone company in Kumla, Sweden, a technician checks phone board circuits under a microscope. This visual check can help uncover defects early on, before this component becomes part of an assembled phone.

www.ericsson.com

Inspection before and after production often involves *acceptance sampling* procedures; monitoring during the production process is referred to as *process control.* Figure 10.2 gives an overview of where these two procedures are applied in the production process.

To determine whether a process is functioning as intended or to verify that a batch or lot of raw materials or final products does not contain more than a specified percentage of defective goods, it is necessary to physically examine at least some of the items in question. The purpose of inspection is to provide information on the degree to which items conform to a standard. The basic issues are

1. How much to inspect and how often.
2. At what points in the process inspection should occur.
3. Whether to inspect in a centralized or on-site location.
4. Whether to inspect attributes (i.e., *count* the number of times something occurs) or variables (i.e., *measure* the value of a characteristic).

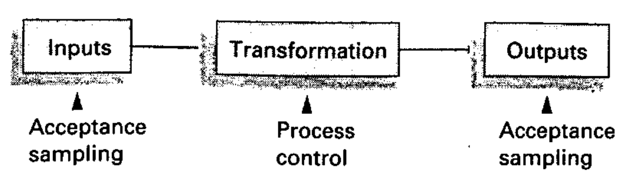
Consider, for example, inspection at an intermediate step in the manufacture of personal computers. Because inspection costs are often significant, questions naturally arise on whether one needs to inspect every computer or whether a small sample of computers will suffice. Moreover, although inspections could be made at numerous points in the production process, it is not generally cost-effective to make inspections at every point. Hence, the question comes up of which points should be designated for inspections. Once these points have been identified, a manager must decide whether to remove the computers from the line and take them to a lab, where specialized equipment might be available to perform certain tests, or to test them where they are being made. We will examine these points in the following sections.

How Much to Inspect and How Often

The amount of inspection can range from no inspection whatsoever to inspection of each item numerous times. Low-cost, high-volume items such as paper clips, roofing nails, and wooden

FIGURE 10.2

Acceptance sampling and process control



pencils often require little inspection because (1) the cost associated with passing defective items is quite low and (2) the processes that produce these items are usually highly reliable, so that defects are rare. Conversely, high-cost, low-volume items that have large costs associated with passing defective products often require more intensive inspections. Thus, critical components of a manned-flight space vehicle are closely scrutinized because of the risk to human safety and the high cost of mission failure. In high-volume systems, *automated* inspection is one option that may be employed.

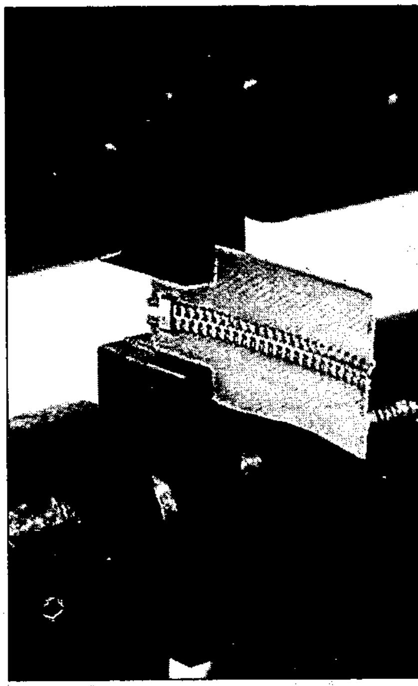
The majority of quality control applications lie somewhere between the two extremes. Most require some inspection, but it is neither possible nor economically feasible to critically examine every part of a product or every aspect of a service for control purposes. The cost of inspection, resulting interruptions of a process or delays caused by inspection, and the manner of testing typically outweigh the benefits of 100 percent inspection. Note that for manual inspection, even 100 percent inspection does not guarantee that all defects will be found and removed. Boredom and fatigue are factors that cause inspection mistakes. However, the cost of letting undetected defects slip through is sufficiently high that inspection cannot be completely ignored. The amount of inspection needed is governed by the costs of inspection and the expected costs of passing defective items. As illustrated in Figure 10.3, if inspection activities increase, inspection costs increase, but the costs of undetected defects decrease. The traditional goal was to minimize the sum of these two costs. In other words, it may not pay to attempt to catch every defect, particularly if the cost of inspection exceeds the penalties associated with letting some defects get through. Current thinking is that every reduction in defective output reduces costs, although not primarily by inspection.

As a rule, operations with a high proportion of human involvement necessitate more inspection effort than mechanical operations, which tend to be more reliable.

The frequency of inspection depends largely on the rate at which a process may go out of control or the number of lots being inspected. A stable process will require only infrequent checks, whereas an unstable one or one that has recently given trouble will require more frequent checks. Likewise, many small lots will require more samples than a few large lots because it is important to obtain sample data from each lot.

Where to Inspect in the Process

Many operations have numerous possible inspection points. Because each inspection adds to the cost of the product or service, it is important to restrict inspection efforts to the points where they can do the most good. In manufacturing, some of the typical inspection points are



A zipper is undergoing a strength test for the bottom stop at the YKK Corporation plant. A leader in the fastener industry, YKK has been in business since 1934, gradually growing to its current 251 plants and offices in 60 countries and over 10,000 employees.

www.ykk.com

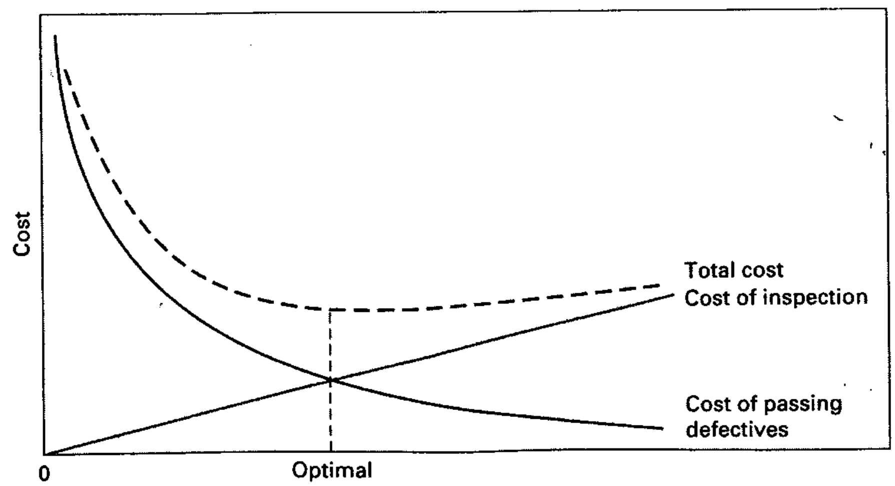


FIGURE 10.3

Traditional view: The amount of inspection is optimal when the sum of the costs of inspection and passing defectives is minimized

1. *Raw materials and purchased parts.* There is little sense in paying for goods that do not meet quality standards and in expending time and effort on material that is bad to begin with.
2. *Finished products.* Customer satisfaction and the firm's image are at stake here, and repairing or replacing products in the field is usually much more costly than doing it at the factory. Likewise, the seller is usually responsible for shipping costs on returns, and payments for goods or service may be held up pending delivery of satisfactory goods or remedial service.
3. *Before a costly operation.* The point is to not waste costly labor or machine time on items that are already defective.
4. *Before an irreversible process.* In many cases, items can be reworked up to a certain point; beyond that point they cannot. For example, pottery can be reworked prior to firing. After that, defective pottery must be discarded or sold as seconds at a lower price.
5. *Before a covering process.* Painting, plating, and assemblies often mask defects.

In the service sector, inspection points are incoming purchased materials and supplies, personnel, service interfaces (e.g., service counter), and outgoing completed work (e.g., repaired appliances). Table 10.1 illustrates a number of examples.

TABLE 10.1
Examples of inspection points in service organizations

Type of Business	Inspection Points	Characteristics
Fast food	Cashier	Accuracy
	Counter area	Appearance, productivity
	Eating area	Cleanliness, no loitering
	Building and grounds	Appearance, safety hazards
	Kitchen	Cleanliness, purity of food, food storage, health regulations
	Parking lot	Safety, good lighting
Hotel/motel	Accounting/billing	Accuracy, timeliness
	Building and grounds	Appearance and safety
	Main desk	Appearance, waiting times, accuracy of bills
	Maid service	Completeness, productivity
	Personnel	Appearance, manners, productivity
	Reservations/occupancy	Over/underbooking, percent occupancy
	Restaurants	Kitchen, menus, meals, bills
	Room service	Waiting time, quality of food
	Supplies	Ordering, receiving, inventories
Supermarket	Cashiers	Accuracy, courtesy, productivity
	Deliveries	Quality, quantity
	Produce	Freshness, ample stock
	Aisles and stockrooms	Uncluttered layout
	Inventory control	Stock-outs
	Shelf stock	Ample supply, rotation of perishables
	Shelf displays	Appearance
	Checkouts	Waiting time
	Shopping carts	Good working condition, ample supply, theft/vandalism
	Parking lot	Safety, good lighting
	Personnel	Appearance, productivity

Centralized versus On-Site Inspection

Some situations require that inspections be performed *on site.* For example, inspecting the hull of a ship for cracks requires inspectors to visit the ship. At other times, specialized tests can best be performed in a lab (e.g., performing medical tests, analyzing food samples, testing metals for hardness, running viscosity tests on lubricants).

The central issue in the decision concerning on-site or lab inspections is whether the advantages of specialized lab tests are worth the time and interruption needed to obtain the results. Reasons favoring on-site inspection include quicker decisions and avoidance of introduction of extraneous factors (e.g., damage or other alteration of samples during transportation to the lab). On the other hand, specialized equipment and a more favorable test environment (less noise and confusion, lack of vibrations, absence of dust, and no workers "helping" with inspections) offer strong arguments for using a lab.

Some companies rely on self-inspections by operators if errors can be traced back to specific operators. This places responsibility for errors at their source (*quality at the source*).

STATISTICAL PROCESS CONTROL

Quality control is concerned with the **quality of conformance** of a process: Does the output of a process conform to the intent of design? Toward that end, managers use **statistical process control** to evaluate the output of a process to determine if it is statistically acceptable. To do this, they take periodic samples from the process and compare them with a predetermined standard.

quality of conformance A product or service conforms to specifications.

statistical process control Statistical evaluation of the output of a process during production.

An important tool in statistical process control is the control chart. A *control chart* is a time-ordered plot of representative sample statistics (e.g., sample means) obtained from an ongoing process. It has upper and lower limits, called *control limits,* that define the range of acceptable (i.e., random) variation for the sample statistic. A control chart is illustrated in Figure 10.4. The purpose of a control chart is to monitor process output to see if it is random. A necessary (but not sufficient) condition for a process to be deemed "in control" or stable, is for all the data points to fall between the upper and lower control limits. Conversely, a data point that falls outside of either limit would be taken as evidence that the process output is nonrandom and, therefore, the process is not "in control." If that happens, the process would be halted to find and correct the cause of the nonrandom variation. The essence of statistical process control is to assure that the output of a process is random so that *future output* will be random.

The Control Process

Sampling and corrective action are only a part of the control process. Effective control requires the following steps:

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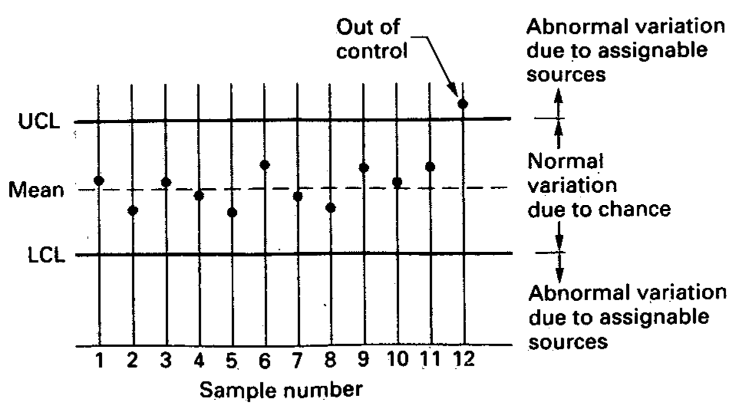
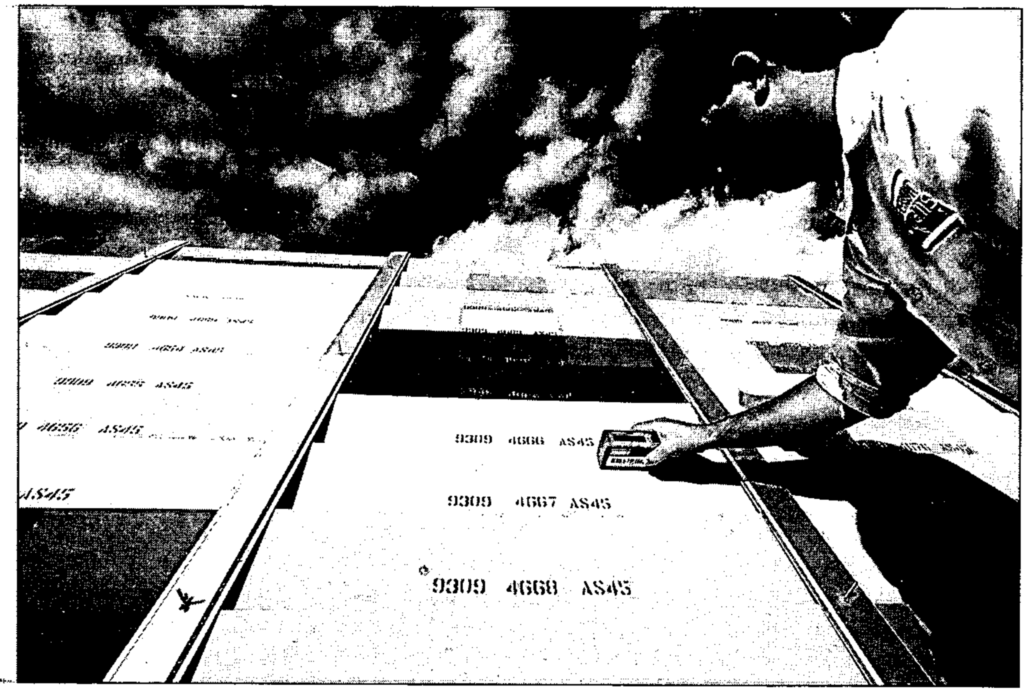


FIGURE 10.4

Example of a control chart

In its product testing, Sherwin-Williams, North America's largest manufacturer of paints and varnishes, tests its paints for longevity and durability, including weathering over time. The company operates more than 2,100 paint stores in the United States, Canada, and Puerto Rico, and is a major supplier for Sears and Wal-Mart.

www.sherwin-williams.com



Define. The first step means to define in sufficient detail what is to be controlled. It is not enough, for example, to simply refer to a painted surface. The paint can have a number of important characteristics such as its thickness, hardness, and resistance to fading or chipping. Different characteristics may require different approaches for control purposes.

Measure. Only those characteristics that can be counted or measured are candidates for control. Thus, it is important to consider how measurement will be accomplished.

Compare. There must be a standard of comparison that can be used to evaluate the measurements. This will relate to the level of quality being sought.

Evaluate. Management must establish a definition of *out of control.* Even a process that is functioning as it should will not yield output that conforms exactly to a standard, simply because of the natural (i.e., random) variations inherent in all processes, manual or mechanical—a certain amount of variation is inevitable. The main task of quality control is to distinguish random from *nonrandom* variability, because nonrandom variability means that a process is out of control.

Correct. When a process is judged out of control, corrective action must be taken. This involves uncovering the cause of nonrandom variability (e.g., worn equipment, incorrect methods, failure to follow specified procedures) and correcting it.

Monitor results. To ensure that corrective action is effective, the output of a process must be monitored for a sufficient period of time to verify that the problem has been eliminated.

In a nutshell, control is achieved by checking a portion of the goods or services, comparing the results to a predetermined standard, evaluating departures from the standard, taking corrective action when necessary, and following up to ensure that problems have been corrected.

Variations and Control

random variation Natural variation in the output of a process, created by countless minor factors.

All processes that provide a good or a service exhibit a certain amount of "natural" variation in their output. The variations are created by the combined influences of countless minor factors, each one so unimportant that even if it could be identified and eliminated, the decrease in process variability would be negligible. In effect, this variability is inherent in the process. It is often referred to as *chance* or **random variation.** In Deming's terms, this is referred to as *common* *variability.* The amount of inherent variability differs from process to process. For instance, older machines generally exhibit a higher degree of natural variability than newer machines, partly because of worn parts and partly because new machines may incorporate design improvements that lessen the variability in their output.

assignable variation In process output, a variation whose cause can be identified.

A second kind of variability in process output is called **assignable variation.** In Deming's terms, this is referred to as *special variation.* Unlike natural variation, the main sources of assignable variation can usually be identified (assigned to a specific cause) and eliminated. Tool wear, equipment that needs adjustment, defective materials, human factors (carelessness, fatigue, noise and other distractions, failure to follow correct procedures, and so on) and problems with measuring devices are typical sources of assignable variation.

When samples of process output are taken, and sample *statistics* such as the sample mean or range are computed, they exhibit the same kind of variability; that is, there is variation in the values of sample means and variation in the values of sample ranges. The variability of a sample statistic can be described by its *sampling distribution,* which is a theoretical distribution that describes the *random* variability of sample statistics.

The goal of sampling is to determine whether nonrandom—and thus, correctable—sources of variation are present in the output of a process. The sampling distribution provides the theoretical basis for accomplishing this. Let's see how this is done.

Suppose there is a process for filling bottles with soft drink. If the amount of soft drink in a large number of bottles is measured accurately, we would discover slight differences among the bottles. If these amounts were arranged on a graph, the frequency distribution would reflect the *process variability.* The values would be clustered close to the process average (e.g., 16 ounces), but some of the values would vary somewhat from the mean.

If we return to the process and take *samples* of 10 bottles each and compute the *mean* amount of soft drink in each sample, we would discover that these values also vary, just as the *individual* values varied. They, too, would have a distribution of values.

If the process contained *only* random variability, the distribution of process values would represent the inherent process variability, and the distribution of sample means would represent the random variability of all possible sample means.

The two distributions are illustrated in Figure 10.5. The sampling distribution exhibits much less variability (i.e., it is less spread out) than the process distribution. This reflects the *averaging* that occurs in computing the sample means: High and low values in samples tend to offset each other, resulting in less variability among sample means than among individual values. Note that both distributions have the same mean; the mean of the sampling distribution is exactly equal to the mean of the process. Finally, note that the sampling distribution is a *normal* distribution, even if the process distribution isn't normal. The *central limit theorem* provides the basis for the assumption that the sampling distribution will be normal or at least approximately normal, even if the population (i.e., the process) is not.

The normal distribution can be used to help judge whether a process is performing adequately. If the output reflects only random variability, one would conclude that the process is *stable* (i.e., in control). But if there is evidence of nonrandom variability, one would conclude that the process is unstable (i.e., out of control). To understand how the normal distribution is used, consider the following: Approximately 95.5 percent of the area under a normal curve (and, hence, 95.5 percent of the sample means) will have values that are within ±2 standard

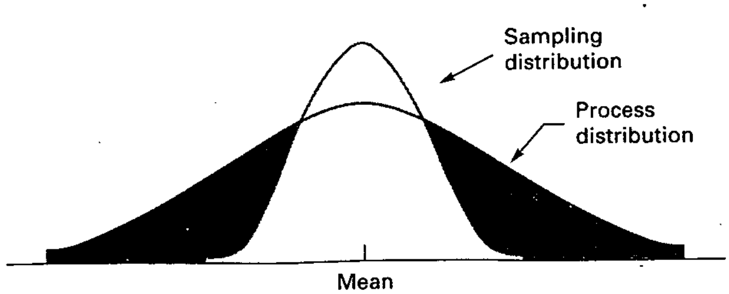


FIGURE 10.5

The sampling distribution of means is normal, and it has less variability than the process

FIGURE 10.6

Percentage of values within given ranges in a normal distribution

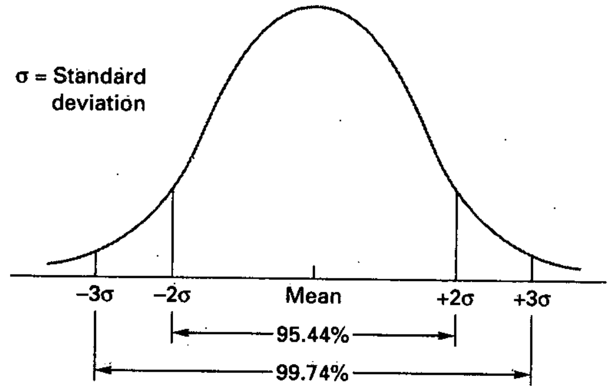
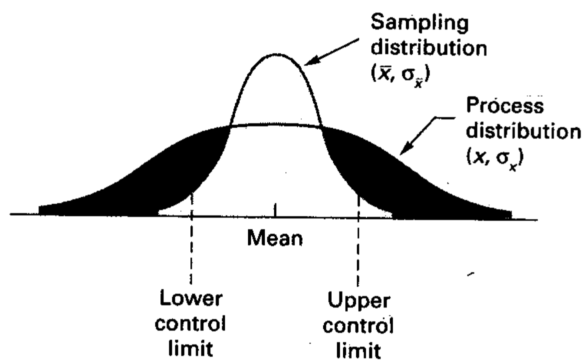


FIGURE 10.7

Control limits are based on the sampling distribution



deviations of the distribution mean, and approximately 99.7 percent of the sample means will have values that are within ±3 standard deviations of the distribution mean. (See Figure 10.6.) These values are typically used for control limits.

Control Charts

control chart A time-ordered plot of sample statistics, used to distinguish between random and nonrandom variability.

A **control chart** is a *time-ordered* plot of sample statistics. It is used to distinguish between random variability and nonrandom variability. The basis for the control chart is the sampling distribution, which essentially describes random variability. There is, however, one minor difficulty relating to the use of a normal sampling distribution. The theoretical distribution extends in either direction to *infinity.* Therefore, *any* value is theoretically possible, even one that is a considerable distance from the mean of the distribution. However, as a practical matter, we know that, say, 99.7 percent of the values will be within ±3 standard deviations of the mean of the distribution. Therefore, we could decide to set the limit, so to speak, at values that represent ±3 standard deviations from the mean, and conclude that any value that was farther away than these limits was a nonrandom variation. In effect, these limits are **control limits:** the dividing lines between what will be designated as random deviations from the mean of the distribution and what will be designated as nonrandom deviations from the mean of the distribution. Figure 10.7 illustrates how control limits are based on the sampling distribution.

control limits The dividing lines between random and nonrandom deviations from the mean of the distribution.

Control charts have two limits that separate random variation and nonrandom variation. The larger value is the *upper control limit* (UCL), and the smaller value is the *lower control limit* (LCL). A sample statistic that falls between these two limits suggests (but does not prove) randomness, while a value outside or on either limit suggests (but does not prove) nonrandomness.

It is important to recognize that because any limits will leave some area in the *tails* of the distribution, there is a small probability that a value will fall outside the limits *even though only random variations are present.* For example, if ±2 sigma (standard deviation) limits are used, they would include 95.5 percent of the values. Consequently, the complement of that number (100 percent − 95.5 percent = 4.5 percent) would not be included. That percentage (or *probability*) is sometimes referred to as the probability of a **Type I error,** where the "error"

Type I error Concluding a process is not in control when it actually is.

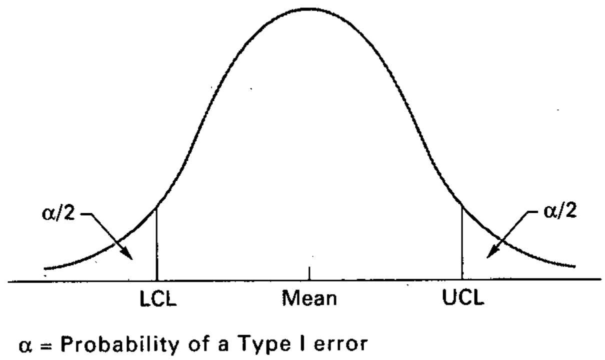


FIGURE 10.8

The probability of a Type I error

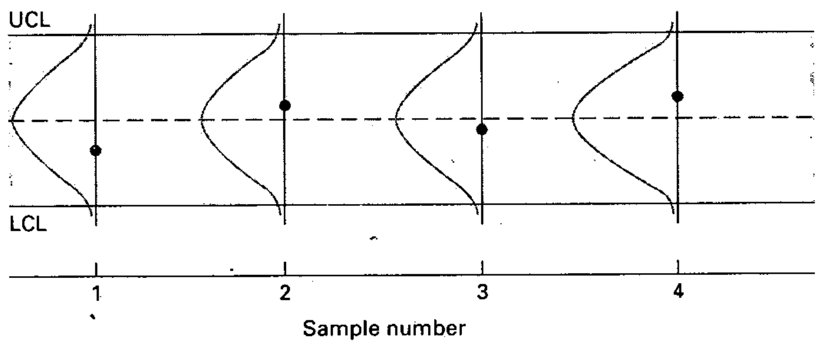


FIGURE 10.9

Each observation is compared to the selected limits of the sampling distribution

is concluding that nonrandomness is present when only randomness is present. It is also referred to as an *alpha* risk, where alpha (α) is the sum of the probabilities in the two tails. Figure 10.8 illustrates this concept.

Using wider limits (e.g., ±3 sigma limits) reduces the probability of a Type I error because it decreases the area in the tails. However, wider limits make it more difficult to detect nonrandom variations *if* they are present. For example, the mean of the process might shift (an assignable cause of variation) enough to be detected by two-sigma limits, but not enough to be readily apparent using three-sigma limits. That could lead to a second kind of error, known as a **Type II error,** which is concluding that a process is in control when it is really out of control (i.e., nonrandom variations are not present, when they are). In theory, the costs of making each error should be balanced by their probabilities. However, in practice, two-sigma limits and three-sigma limits are commonly used without specifically referring to the probability of a Type II error.

Type II error Concluding a process is in control when it is not.

Each sample is represented by a single value (e.g., the sample mean) on a control chart. Moreover, each value is compared to the extremes of the sampling distribution (the control limits) to judge if it is within the acceptable (random) range. Figure 10.9 illustrates this concept.

There are four commonly used control charts. Two are used for **variables,** and two are used for **attributes.** Attribute data are *counted* (e.g., the number of defective parts in a sample, the number of calls per day); variables data are *measured,* usually on a continuous scale (e.g., amount of time needed to complete a task, length or width of a part).

variables Generate data that are *measured.*

attributes Generate data that are *counted.*

The two control charts for variables data are described in the next section, and the two control charts for attribute data are described in the section following that.

Control Charts for Variables

Mean and range charts are used to monitor variables. Control charts for means monitor the *central tendency* of a process, and range charts monitor the *dispersion* of a process.

Mean Charts A **mean control chart,** sometimes referred to as an $\bar{x}$ ("x-bar") chart, is based on a normal distribution. It can be constructed in one of two ways. The choice depends on what information is available. Although the value of the standard deviation of a process, σ, is

mean control chart Control chart used to monitor the central tendency of a process.

often unknown, if a reasonable estimate is available, one can compute control limits using these formulas:

$$\begin{aligned} \text{Upper control limit (UCL): } &= \bar{\bar{x}} + z\sigma_{\bar{x}} \\ \text{Lower control limit (LCL): } &= \bar{\bar{x}} - z\sigma_{\bar{x}} \end{aligned} \qquad (10\text{–}1)$$

where

$\sigma_{\bar{x}} = \sigma/\sqrt{n}$

$\sigma_{\bar{x}}$ = Standard deviation of distribution of sample means

σ = Process standard deviation

n = Sample size

z = Standard normal deviate

$\bar{\bar{x}}$ = Average of sample means

The following example illustrates the use of these formulas.

EXAMPLE 1

A quality inspector took five samples, each with four observations, of the length of time for glue to dry. The analyst computed the mean of each sample and then computed the grand mean. All values are in minutes. Use this information to obtain three-sigma (i.e., z=3) control limits for means of future times. It is known from previous experience that the standard deviation of the process is .02 minute.

		SAMPLE				
		1	**2**	**3**	**4**	**5**
	1	12.11	12.15	12.09	12.12	12.09
Observation	**2**	12.10	12.12	12.09	12.10	12.14
	3	12.11	12.10	12.11	12.08	12.13
	4	12.08	12.11	12.15	12.10	12.12
	$\bar{x}$	12.10	12.12	12.11	12.10	12.12

SOLUTION

$$\bar{\bar{x}} = \frac{12.10 + 12.12 + 12.11 + 12.10 + 12.12}{5} = 12.11$$

Using Formula 10–1, with $z = 3$, $n = 4$ observations per sample, and $\sigma = .02$, we find

$$\text{UCL: } 12.11 + 3\left(\frac{.02}{\sqrt{4}}\right) = 12.14$$

$$\text{LCL: } 12.11 - 3\left(\frac{.02}{\sqrt{4}}\right) = 12.08$$

Note: If one applied these control limits to the means, one would judge the process to be *in control* because all of the sample means have values that fall within the control limits. The fact that some of the *individual* measurements fall outside of the control limits (e.g., the first observation in Sample 2 and the last observation in Sample 3) is irrelevant. You can see why by referring to Figure 10.8: *Individual* values are represented by the process distribution, a large portion of which lies outside of the control limits for *means.*

A second approach is to use the sample *range* as a measure of process variability. The appropriate formulas for control limits are

$$\begin{aligned} \text{UCL} &= \bar{\bar{x}} + A_2\bar{R} \\ \text{LCL} &= \bar{\bar{x}} - A_2\bar{R} \end{aligned} \qquad (10\text{–}2)$$

where

A_2 = A factor from Table 10.2

$\bar{R}$ = Average of sample ranges

EXAMPLE 2

Twenty samples of $n = 8$ have been taken from a cleaning operation. The average sample range for the 20 samples was .016 minute, and the average mean was 3 minutes. Determine three-sigma control limits for this process.

SOLUTION

$\bar{\bar{x}} = 3$ cm, $\bar{R} = .016$, $A_2 = .37$ for $n = 8$ (from Table 10.2)

$$\text{UCL} = \bar{\bar{x}} + A_2\bar{R} = 3 + .37(.016) = 3.006 \text{ minutes}$$
$$\text{LCL} = \bar{\bar{x}} - A_2\bar{R} = 3 - .37(.016) = 2.994 \text{ minutes}$$

Note that this approach assumes that the range is in control.

Range Charts **Range control charts** (R-charts) are used to monitor process dispersion; they are sensitive to changes in process dispersion. Although the underlying sampling distribution is not normal, the concepts for use of range charts are much the same as those for use of mean charts. Control limits for range charts are found using the average sample range in conjunction with these formulas:

range control chart Control chart used to monitor process dispersion.

$$\text{UCL} = D_4\bar{R}$$
$$\text{LCL} = D_3\bar{R} \qquad (10\text{–}3)$$

where values of D_3 and D_4 are obtained from Table 10.2.[1]

TABLE 10.2
Factors for three-sigma control limits for $\bar{x}$ and R charts

Number of Observations in Subgroup, n	Factor for $\bar{x}$ Chart, A_2	FACTORS FOR R CHARTS: Lower Control Limit, D_3	FACTORS FOR R CHARTS: Upper Control Limit, D_4
2	1.88	0	3.27
3	1.02	0	2.57
4	0.73	0	2.28
5	0.58	0	2.11
6	0.48	0	2.00
7	0.42	0.08	1.92
8	0.37	0.14	1.86
9	0.34	0.18	1.82
10	0.31	0.22	1.78
11	0.29	0.26	1.74
12	0.27	0.28	1.72
13	0.25	0.31	1.69
14	0.24	0.33	1.67
15	0.22	0.35	1.65
16	0.21	0.36	1.64
17	0.20	0.38	1.62
18	0.19	0.39	1.61
19	0.19	0.40	1.60
20	0.18	0.41	1.59

Source: Adapted from Eugene Grant and Richard Leavenworth, *Statistical Quality Control,* 5th ed. Copyright © 1980 McGraw-Hill Companies, Inc. Used with permission.

[1]If the process standard deviation is known, control limits for a range chart can be calculated using values from Table 10.2

$$\text{LCL} = \frac{3D_3\sigma}{A_2\sqrt{n}}, \qquad \text{UCL} = \frac{3D_4\sigma}{A_2\sqrt{n}}$$

EXAMPLE 3

Twenty-five samples of $n = 10$ observations have been taken from a milling process. The average sample range was .01 centimeter. Determine upper and lower control limits for sample ranges.

SOLUTION

$\bar{R} = .01$ cm, $n = 10$

From Table 10.2, for $n = 10$, $D_4 = 1.78$ and $D_3 = .22$.

$UCL_R = 1.78(.01) = .0178$ or .018

$LCL_R = .22(.01) = .0022$ or .002

In Example 3, a sample range of .018 centimeter or more would suggest that the process variability had increased. A sample range of .002 or less would imply that the process variability had decreased. In the former case, this means that the process was producing too much variation; we would want to investigate this in order to remove the cause of variation. In the latter case, even though decreased variability is desirable, we would want to determine what was causing it: Perhaps an improved method has been used, in which case we would want to identify it. Possibly the improved quality has come at the expense of productivity, or this was only a random occurrence. Hence, it can be beneficial to investigate points beyond the lower limit as well as points beyond the upper limit in a range chart.

Using Mean and Range Charts Mean control charts and range control charts provide different perspectives on a process. As we have seen, mean charts are sensitive to shifts in the process mean, whereas range charts are sensitive to changes in process dispersion. Because of this difference in perspective, both types of charts might be used to monitor the same process. The logic of using both is readily apparent in Figure 10.10. In Figure 10.10A, the mean chart picks up the shift in the process mean, but because the dispersion is not changing, the range chart fails to indicate a problem. Conversely, in Figure 10.10B, a change in process dispersion is less apt to be detected by the mean chart than by the range chart. Thus, use of both charts provides more complete information than either chart alone. Even so, a single chart may suffice in some cases. For example, a process may be more susceptible to changes in the process mean than to changes in dispersion, so it might be unnecessary to monitor dispersion. Because of the time and cost of constructing control charts, gathering the necessary data, and evaluating the results, only those aspects of a process that tend to cause problems should be monitored.

Once control charts have been set up, they can serve as a basis for deciding when to interrupt a process and search for assignable causes of variation. To determine initial control limits, one can use the following procedure.

1. Obtain 20 to 25 samples. Compute the appropriate sample statistic(s) for each sample (e.g., mean).
2. Establish preliminary control limits using the formulas.
3. Determine if any points fall outside the control limits.
4. If you find no out-of-control signals, assume that the process is in control. If not, investigate and correct assignable causes of variation. Then resume the process and collect another set of observations upon which control limits can be based.
5. Plot the data on the control chart and check for out-of-control signals.

Control Charts for Attributes

Control charts for attributes are used when the process characteristic is *counted* rather than measured. For example, the number of defective items in a sample is counted, whereas the length of each item is measured. There are two types of attribute control charts, one for the fraction of defective items in a sample (a p-chart) and one for the number of defects per unit (a c-chart). A *p-chart* is appropriate when the data consist of two categories of items. For instance,

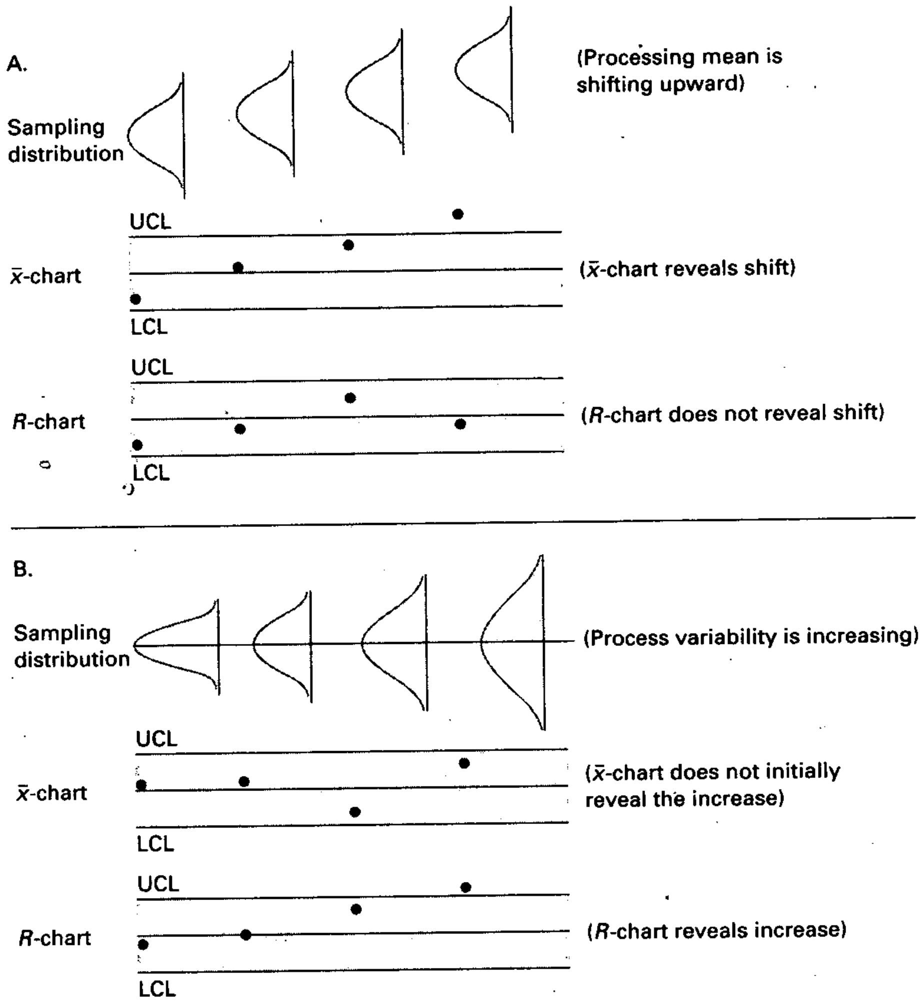


FIGURE 10.10

Mean and range charts used together complement each other

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if glass bottles are inspected for chipping and cracking, both the good bottles and the defective ones can be counted. However, one can count the number of accidents that occur during a given period of time but *not* the number of accidents that did not occur. Similarly, one can count the number of scratches on a polished surface, the number of bacteria present in a water sample, and the number of crimes committed during the month of August, but one cannot count the number of nonoccurrences. In such cases, a *c-chart* is appropriate. See Table 10.3.

p-Chart A ***p*-chart** is used to monitor the proportion of defective items generated by a process. The theoretical basis for a *p*-chart is the binomial distribution, although for large sample sizes, the normal distribution provides a good approximation to it. Conceptually, a *p*-chart is constructed and used in much the same way as a mean chart.

***p*-chart** Control chart for attributes, used to monitor the proportion of defective items in a process.

The center line on a *p*-chart is the average fraction defective in the population, p. The standard deviation of the sampling distribution when p is known is

$$\sigma_p = \sqrt{\frac{p(1-p)}{n}}$$

Control limits are computed using the formulas

$$\begin{aligned} \text{UCL}_p &= p + z\sigma_p \\ \text{LCL}_p &= p - z\sigma_p \end{aligned} \qquad (10\text{–}4)$$

If p is unknown, it can be estimated from samples. That estimate, $\bar{p}$, replaces p in the preceding formulas, and $\hat{\sigma}_p$ replaces σ_p, as illustrated in Example 4.

TABLE 10.3
p-chart or *c*-chart?

The following tips should help you select the type of control chart, a *p*-chart or a *c*-chart, that is appropriate for a particular application:

Use a *p*-chart:

1. When observations can be placed into one of *two* categories. Examples include items (observations) that can be classified as
   a. Good or bad.
   b. Pass or fail.
   c. Operate or don't operate.
2. When the data consist of multiple samples of *n* observations each (e.g., 15 samples of $n = 20$ observations each).

Use a *c*-chart:

When only the number of occurrences per unit of measure can be counted; nonoccurrences cannot be counted. Examples of occurrences and units of measure include
a. Scratches, chips, dents, or errors per item.
b. Cracks or faults per unit of distance (e.g., meters, miles).
c. Breaks or tears, per unit of area (e.g., square yard, square meter).
d. Bacteria or pollutants per unit of volume (e.g., gallon, cubic foot, cubic yard).
e. Calls, complaints, failures, equipment breakdowns, or crimes per unit of time (e.g., hour, day, month, year).

Note: Because the formula is an approximation, it sometimes happens that the computed LCL is negative. In those instances, zero is used as the lower limit.

EXAMPLE 4

An inspector counted the number of defective monthly billing statements of a company telephone in each of 20 samples. Using the following information, construct a control chart that will describe 99.74 percent of the chance variation in the process when the process is in control. Each sample contained 100 statements.

Sample	Number of Defectives	Sample	Number of Defectives
1	4	11	8
2	10	12	12
3	12	13	9
4	3	14	10
5	9	15	21
6	11	16	10
7	10	17	8
8	22	18	12
9	13	19	10
10	10	20	16
			220

SOLUTION

z for 99.74 percent is 3.00 (from Appendix Table A).

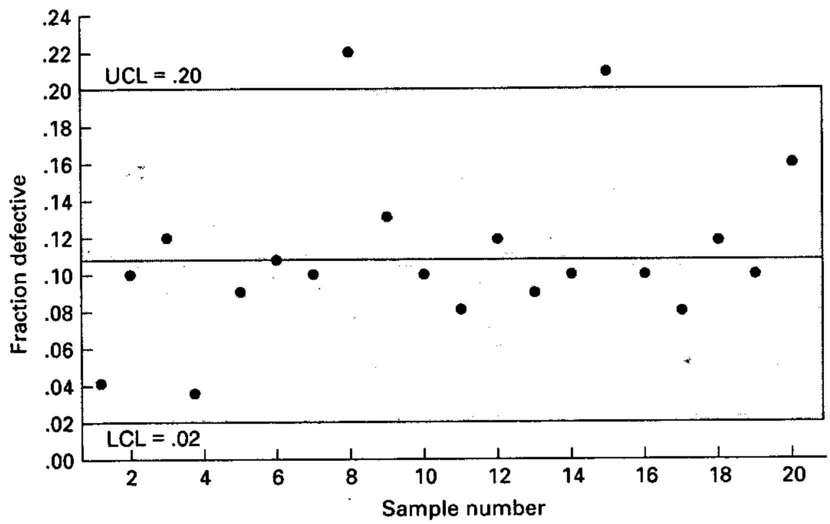
$$\bar{p} = \frac{\text{Total number of defectives}}{\text{Total number of observations}} = \frac{220}{20(100)} = .11$$

$$\hat{\sigma}_p = \sqrt{\frac{\bar{p}(1-\bar{p})}{n}} = \sqrt{\frac{.11(1-.11)}{100}} = .03$$

Control limits are

$$\text{UCL}_p = \bar{p} + z(\hat{\sigma}_p) = .11 + 3.00(.03) = .20$$
$$\text{LCL}_p = \bar{p} - z(\hat{\sigma}_p) = .11 - 3.00(.03) = .02$$

Plotting the control limits and the sample fraction defective, you can see that the process is not in control: sample 8 (22/100 = .22) and sample 15 (21/100 = .21) are above the upper control limit.



c-Chart When the goal is to control the number of *occurrences* (e.g., defects) *per unit,* a **c-chart** is used. Units might be automobiles, hotel rooms, typed pages, or rolls of carpet. The underlying sampling distribution is the Poisson distribution. Use of the Poisson distribution assumes that defects occur over some *continuous* region and that the probability of more than one defect at any particular point is negligible. The mean number of defects per unit is c and the standard deviation is $\sqrt{c}$. For practical reasons, the normal approximation to the Poisson is used. The control limits are

c-chart Control chart for attributes, used to monitor the number of defects per unit.

$$\text{UCL}_c = c + z\sqrt{c}$$
$$\text{LCL}_c = c - z\sqrt{c} \qquad (10\text{–}5)$$

If the value of c is unknown, as is generally the case, the sample estimate, $\bar{c}$, is used in place of c, using $\bar{c}$ = Number of defects ÷ Number of samples.

EXAMPLE 5

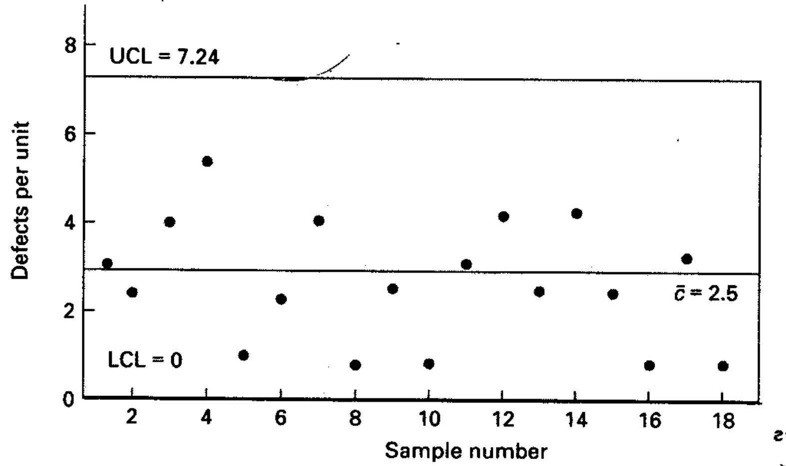
Rolls of coiled wire are monitored using a c-chart. Eighteen rolls have been examined, and the number of defects per roll has been recorded in the following table. Is the process in control? Plot the values on a control chart using three standard deviation control limits.

Sample	Number of Defects	Sample	Number of Defects
1	3	10	1
2	2	11	3
3	4	12	4
4	5	13	2
5	1	14	4
6	2	15	2
7	4	16	1
8	1	17	3
9	2	18	1
			45

SOLUTION

$\bar{c} = 45/18 = 2.5$ = average number of defects per coil

$$\text{UCL}_c = \bar{c} + 3\sqrt{\bar{c}} = 2.5 + 3\sqrt{2.5} = 7.24$$
$$\text{LCL}_c = \bar{c} - 3\sqrt{\bar{c}} = 2.5 - 3\sqrt{2.5} = -2.24 \rightarrow 0$$



When the computed lower control limit is negative, the effective lower limit is zero. The calculation sometimes produces a negative lower limit due to the use of the normal distribution to approximate the Poisson distribution: The normal is symmetrical, whereas the Poisson is not symmetrical when c is close to zero.

Note that if an observation falls below the lower control limit on a p-chart or a c-chart, the cause should be investigated, just as it would be for a mean or range chart, even though such a point would imply that the process is exhibiting better than expected quality. It may turn out to be the result of an undesirable overuse of resources. On the other hand, it may lead to a discovery that can improve the quality of process.

In Landes, France, an expert removes a plug of Roquefort cheese for testing. A quality judgment is made purely on sight, testing for coloration and consistency. The testers never actually taste the cheese.

Managerial Considerations concerning Control Charts

Using control charts adds to the cost and time needed to obtain output. Ideally a process is so good that the desired level of quality could be achieved without the use of any control charts. The best organizations strive to reach this level, but many are not yet there, so they employ control charts at various points in their processes. In those organizations, managers must make a number of important decisions about the use of control charts:

1. At what points in the process to use control charts.
2. What size samples to take.
3. What type of control chart to use (i.e., variables or attribute).

The decision about where to use control charts should focus on those aspects of the process that (1) have a tendency to go out of control and (2) are critical to the successful operation of the product or service.

Sample size is important for two reasons. One is that cost and time are functions of sample size; the greater the sample size, the greater the cost to inspect those items (and the greater the lost product if destructive testing is involved) and the longer the process must be held up while waiting for the results of sampling. The second reason is that smaller samples are more likely to reveal a change in the process than larger samples because a change is more likely to take place *within* the large sample, but *between* small samples. Consequently, a sample statistic such as the sample mean in the large sample could combine both "before-change" and "after-change" observations, whereas in two smaller samples, the first could contain "before" observations and the second "after" observations, making detection of the change more likely.

In some instances, a manager can choose between using a control chart for variables (a mean chart) and a control chart for attributes (a p-chart). If the manager is monitoring the diameter of a drive shaft, either the diameter could be measured and a mean chart used for control, or the shafts could be inspected using a *go, no-go gauge*—which simply indicates whether a particular shaft is within specification without giving its exact dimensions—and

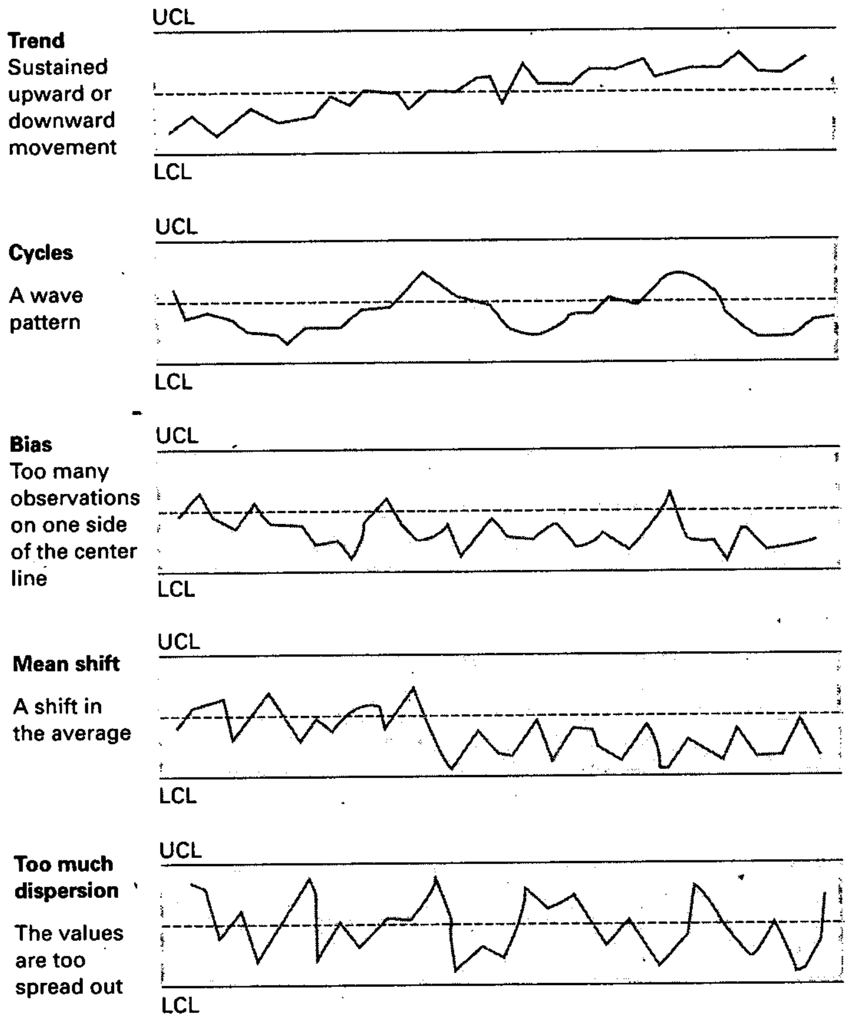


FIGURE 10.11

Some examples of nonrandom patterns in control chart plots

a *p*-chart could be used. Measuring is more costly and time-consuming per unit than the yes-no inspection using a go, no-go gauge, but because measuring supplies more information than merely counting items as good or bad, one needs a much smaller sample size for a mean chart than a *p*-chart. Hence, a manager must weigh the time and cost of sampling against the information provided.

Run Tests

Control charts test for points that are too extreme to be considered random (e.g., points that are more than three standard deviations from the mean). However, even if all points are within the control limits, the data may still not reflect a random process. In fact, any sort of pattern in the data would suggest a nonrandom process. Figure 10.11 illustrates some patterns that might be present.

Analysts often supplement control charts with a **run test,** which is another kind of test for randomness. This enables an analyst to do a better job of detecting abnormalities in a process and provides insights into correcting a process that is out of control. A variety of run tests are available; this section describes two that are widely used.

run test A test for randomness.

When a process is stable or in statistical control, the output it generates will exhibit random variability over a period of time. The presence of patterns, such as trends, cycles, or bias in the output indicates that assignable, or nonrandom, causes of variation exist. Hence, a process that produces output with such patterns is not in a state of statistical control. This is true even though all points on a control chart may be within the control limits. For this

FIGURE 10.12

Counting above/below median runs

Counting Above/Below Median Runs

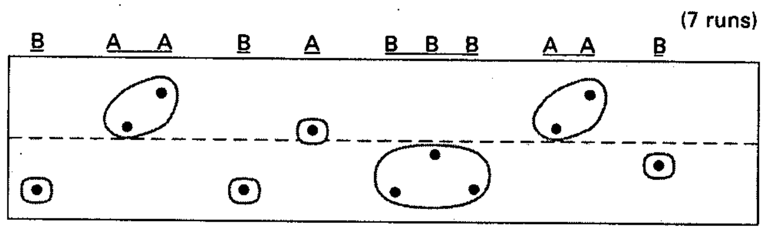
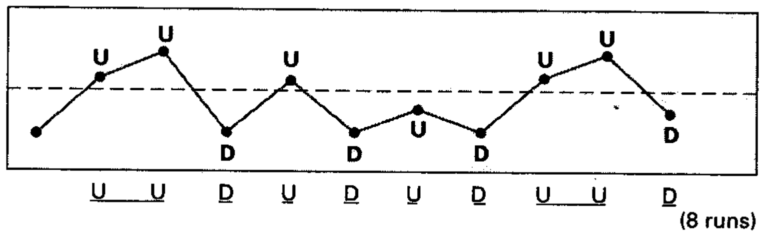


FIGURE 10.13

Counting up/down runs

Counting Up/Down Runs



reason, it is usually prudent to subject control chart data to run tests to determine whether patterns can be detected.

run Sequence of observations with a certain characteristic.

A **run** is defined as a sequence of observations with a certain characteristic, followed by one or more observations with a different characteristic. The characteristic can be anything that is observable. For example, in the series A A A B, there are two runs: a run of three As followed by a run of one B. Underlining each run helps in counting them. In the series A A B B B A, the underlining indicates three runs.

Two useful run tests involve examination of the number of runs *up and down* and runs above and below the *median.*[2] In order to count these runs, the data are transformed into a series of Us and Ds (for *up* and *down*) and into a series of As and Bs (for *above* and *below* the median). Consider the following sequence, which has a median of 36.5. The first two values are below the median, the next two are above it, the next to last is below, and the last is above. Thus, there are four runs:

25	29	42	40	35	38
B	B	A	A	B	A

In terms of up and down, there are three runs in the same data. The second value is up from the first value, the third is up from the second, the fourth is down from the third, and so on:

25	29	42	40	35	38
—	U	U	D	D	U

(The first value does not receive either a U or a D because nothing precedes it.)

If a plot is available, the runs can be easily counted directly from the plot, as illustrated in Figures 10.12 and 10.13.

To determine whether any patterns are present in control chart data, one must transform the data into both As and Bs and Us and Ds, and then count the number of runs in each case. These numbers must then be compared with the number of runs that would be expected in a completely

[2]The median and mean are approximately equal for control charts. The use of the median depends on its ease of determination; use the mean instead of the median if it is given.

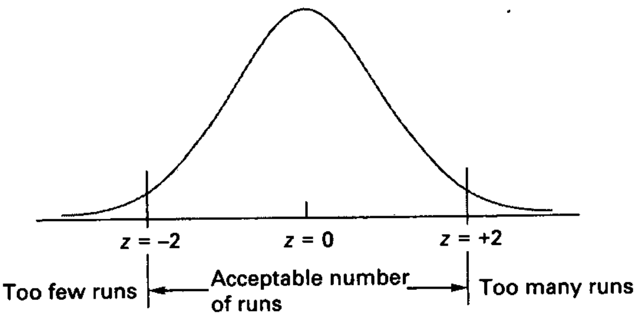


FIGURE 10.14

A sampling distribution for runs is used to distinguish chance variation from patterns

random series. For both the median and the up/down run tests, the expected number of runs is a function of the number of observations in the series. The formulas are

$$E(r)_{med} = \frac{N}{2} + 1 \qquad (10\text{–}6a)$$

$$E(r)_{u/d} = \frac{2N-1}{3} \qquad (10\text{–}7a)$$

where N is the number of observations or data points, and $E(r)$ is the expected number of runs.

The actual number of runs in any given set of observations will vary from the expected number, due to chance and any patterns that might be present. Chance variability is measured by the standard deviation of runs. The formulas are

$$\sigma_{med} = \sqrt{\frac{N-1}{4}} \qquad (10\text{–}6b)$$

$$\sigma_{u/d} = \sqrt{\frac{16N-29}{90}} \qquad (10\text{–}7b)$$

Distinguishing chance variability from patterns requires use of the sampling distributions for median runs and up/down runs. Both distributions are approximately normal. Thus, for example, 95.5 percent of the time a random process will produce an observed number of runs within two standard deviations of the expected number. If the observed number of runs falls in that range, there are probably no nonrandom patterns; for observed numbers of runs beyond such limits, we begin to suspect that patterns are present. Too few or too many runs can be an indication of nonrandomness.

In practice, it is often easiest to compute the number of standard deviations, z, by which an observed number of runs differs from the expected number. This z value would then be compared to the value ± 2 (z for 95.5 percent) or some other desired value (e.g., ± 1.96 for 95 percent, ± 2.33 for 98 percent). A test z that exceeds the desired limits indicates patterns are present. (See Figure 10.14.) The computation of z takes the form

$$z_{test} = \frac{\text{Observed number of runs} - \text{Expected number of runs}}{\text{Standard deviation of number of runs}}$$

For the median and up/down tests, one can find z using these formulas:

Median: $$z = \frac{r - [(N/2) + 1]}{\sqrt{(N-1)/4}} \qquad (10\text{–}8)$$

Up and down: $$z = \frac{r - [(2N-1)/3]}{\sqrt{(16N-29)/90}} \qquad (10\text{–}9)$$

where

N = Total number of observations

r = Observed number of runs of either As and Bs or Us and Ds, depending on which test is involved.

It is desirable to apply both run tests to any given set of observations because each test is different in terms of the types of patterns it can detect. Sometimes both tests will pick up a certain pattern, but sometimes only one will detect nonrandomness. If either does, the implication is that some sort of nonrandomness is present in the data.

EXAMPLE 6

Twenty sample means have been taken from a process. The means are shown in the following table. Use median and up/down run tests with $z = 2$ to determine if assignable causes of variation are present. Assume the median is 11.0.

SOLUTION

The means are marked according to above/below the median and up/down. The solid lines represent the runs.

Sample	A/B	Mean	U/D	Sample	A/B	Mean	U/D
1	B	10.0	—	11	B	10.7	D
2	B	10.4	U	12	A	11.3	U
3	B	10.2	D	13	B	10.8	D
4	A	11.5	U	14	A	11.8	U
5	B	10.8	D	15	A	11.2	D
6	A	11.6	U	16	A	11.6	U
7	A	11.1	D	17	A	11.2	D
8	A	11.2	U	18	B	10.6	D
9	B	10.6	D	19	B	10.7	U
10	B	10.9	U	20	A	11.9	U

A/B: 10 runs U/D: 17 runs

The expected number of runs for each test is

$$E(r)_{\text{med}} = \frac{N}{2} + 1 = \frac{20}{2} + 1 = 11$$

$$E(r)_{u/d} = \frac{2N - 1}{3} = \frac{2(20) - 1}{3} = 13$$

The standard deviations are

$$\sigma_{\text{med}} = \sqrt{\frac{N-1}{4}} = \sqrt{\frac{20-1}{4}} = 2.18$$

$$\sigma_{u/d} = \sqrt{\frac{16N-29}{90}} = \sqrt{\frac{16(20)-29}{90}} = 1.80$$

The z_{test} values are

$$z_{\text{med}} = \frac{10 - 11}{2.18} = -.46$$

$$z_{u/d} = \frac{17 - 13}{1.80} = +2.22$$

Although the median test does not reveal any pattern, because its z_{test} value is within the range ± 2, the up/down test does; its value exceeds $+2$. Consequently, nonrandom variations are probably present in the data and, hence, the process is not in control.

If ties occur in either test (e.g., a value equals the median or two values in a row are the same), assign A/B or U/D in such a manner that that z_{test} is as large as possible. If z_{test} still does not exceed ± 2 (± 1.96, etc.), you can be reasonably confident that a conclusion of randomness is justified.

PROCESS CAPABILITY

The variability of a process can significantly impact quality. Three commonly used terms refer to the variability of process output. Each term relates to a slightly different aspect of that variability, so it is important to differentiate these terms.

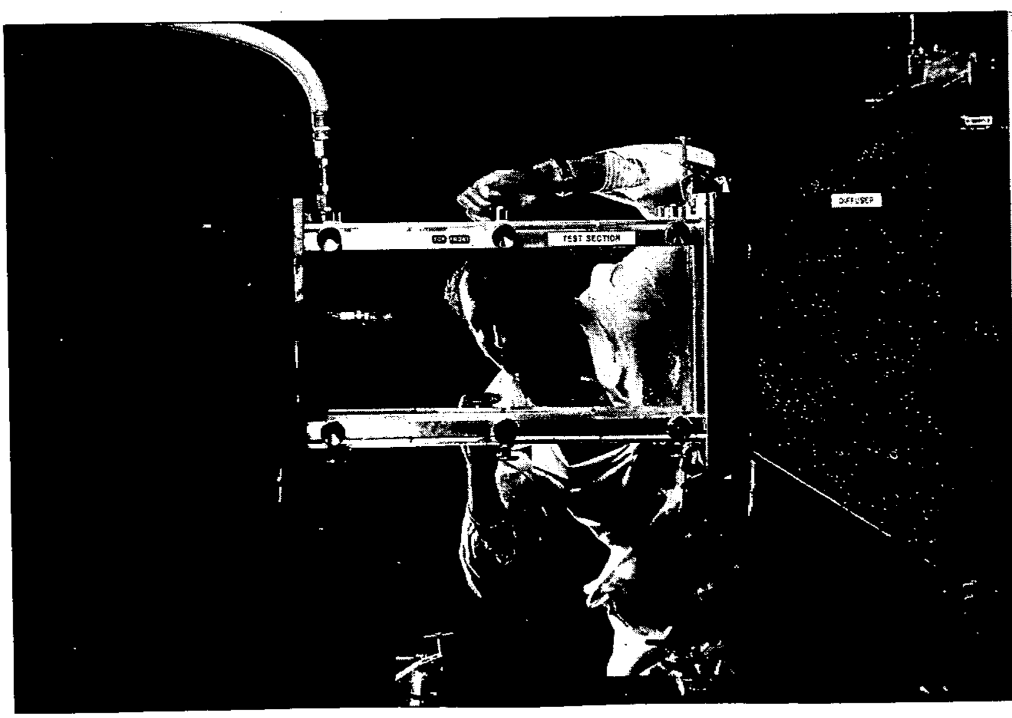
> **Specifications** or *tolerances* are established by engineering design or customer requirements. They indicate a range of values in which individual units of output must fall in order to be acceptable.
>
> **Control limits** are statistical limits that reflect the extent to which *sample statistics* such as means and ranges can vary due to randomness alone.
>
> **Process variability** reflects the natural or inherent (i.e., random) variability in a process. It is measured in terms of the process standard deviation.

specifications A range of acceptable values established by engineering design or customer requirements.

process variability Natural or inherent variability in a process.

Control limits and process variability are directly related: control limits are based on sampling variability, and sampling variability is a function of process variability. On the other hand, there is *no* direct link between specifications and either control limits or process variability. They are specified in terms of the output of a product or service, not in terms of the *process* by which the output is generated. Hence, in a given instance, the output of a process may or may not conform to specifications, even though the process may be statistically in control. That is why it is also necessary to take into account the *capability* of a process. The term **process capability** refers to the inherent variability of process output *relative to* the variation allowed by the design specifications. The following section describes capability analysis.

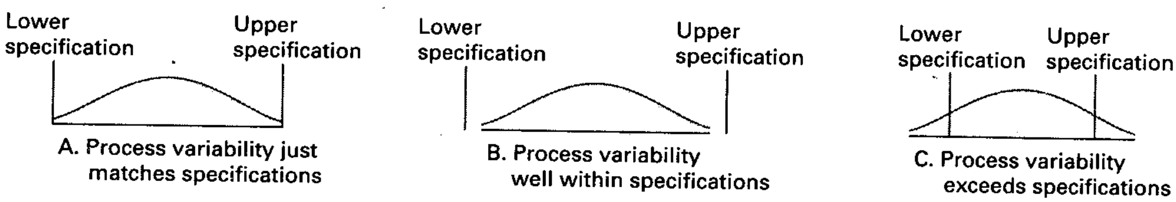
process capability The inherent variability of process output relative to the variation allowed by the design specification.



As a quality control measure, wind tunnel testing is done for a crop duster to check the aerial dispersal of liquid chemicals over crops at various aircraft speeds. The aircraft have wind-driven pumps under the fuselage that push liquids through booms—mounted at the edge of the wings—for dispersal through specially designed nozzles.

FIGURE 10.15

Process capability and specifications may or may not match



Capability Analysis

Capability analysis is the determination of whether the variability inherent in the output of a process falls within the acceptable range of variability allowed by the design specifications for the process output. If it is within the specifications, the process is said to be "capable." If it is not, the manager must decide how to correct the situation.

Consider the three cases illustrated in Figure 10.15. In the first case, process capability and output specifications are well matched, so that nearly all of the process output can be expected to meet the specifications. In the second case, the process variability is much less than what is called for, so that virtually 100 percent of the output should be well within tolerance. In the third case, however, the specifications are tighter than what the process is capable of, so that even when the process is functioning as it should, a sizable percentage of the output will fail to meet the specifications. In other words, the process could be in control and still generate unacceptable output. Thus, we cannot automatically assume that a process that is in control will provide desired output. Instead, we must specifically check whether a process is *capable* of meeting specifications and not simply set up a control chart to monitor it. A process should be both in control and within specifications *before* production begins—in essence, "Set the toaster correctly at the start. Don't burn the toast and then scrape it!"

In instances such as case C in Figure 10.15, a manager might consider a range of possible solutions: (1) redesign the process so that it can achieve the desired output, (2) use an alternative process that can achieve the desired output, (3) retain the current process but attempt to eliminate unacceptable output using 100 percent inspection, and (4) examine the specifications to see whether they are necessary or could be relaxed without adversely affecting customer satisfaction.

Obviously, process variability is the key factor in process capability. It is measured in terms of the process standard deviation. To determine whether the process is capable, compare ± 3 standard deviations (i.e., 6 standard deviations) of the process to the specifications for the process. For example, suppose the ideal length of time to perform a service is 10 minutes, and an acceptable range of variation around this time is ± 1 minute. If the process has a standard deviation of .5 minute, it would not be capable because ± 3 standard deviations would be ± 1.5 minutes, exceeding the specification of ± 1 minute.

EXAMPLE 7

A manager has the option of using any one of three machines for a job. The machines and their standard deviations are listed below. Determine which machines are capable if the specifications are 10.00 mm and 10.80 mm.

Machine	Standard Deviation (mm)
A	0.13
B	0.08
C	0.16

SOLUTION

Determine the capability of each machine (i.e., 6 standard deviations) and compare that value to the specification *difference* of .80 mm.

Machine	Standard Deviation (mm)	Machine Capability
A	0.13	0.78
B	0.08	0.48
C	0.16	0.96

C_p

To express the capability of a machine or process, some companies use the ratio of the specification width to the process capability. It can be computed using the following formula:

$$\text{Process capability ratio, } C_p = \frac{\text{Specification width}}{\text{Process width}} = \frac{\text{Upper specification} - \text{Lower specification}}{6\sigma} \qquad (10\text{–}10)$$

For a process to be deemed to be capable, it must have a capability ratio of at least 1.33. A ratio of 1.33 implies only about 30 parts per million can be expected to not be within the specifications. Moreover, the greater the capability ratio, the greater the probability that the output of a machine or process will fall within design specifications.

EXAMPLE 8

Compute the process capability index for each machine in Example 7.

SOLUTION

The specification width in Example 7 is .80 mm. Hence, to determine the capability index for each machine, divide .80 by the process width (i.e., 6 standard deviations) of each machine. The results are shown in the following table:

Machine	Standard Deviation (mm)	Machine Capability	C_p
A	0.13	0.78	0.80/0.78 = 1.03
B	0.08	0.48	0.80/0.48 = 1.67
C	0.16	0.96	0.80/0.96 = 0.83

We can see that only machine B is capable because its ratio is not less than 1.33. See Figure 10.15 for a visual portrayal of these results.

The Motorola Corporation is well known for its use of the term *six sigma,* which refers to its goal of achieving a process variability so small that the design specifications represent six standard deviations above *and* below the process mean. That means a process capability ratio equal to 2.00, resulting in an extremely small probability of getting any output not within the design specifications. This is illustrated in Figure 10.16.

To get an idea of how a capability ratio of 2.00 compares to a ratio of, say, 1.00 in terms of defective items, consider that if the U.S. Postal Service had a capability ratio of 1.00 for delivery errors of first-class mail, this would translate into about 10,000 misdelivered pieces per day; if the capability ratio was 2.00, that number would drop to about 1,000 pieces a day.

Care must be taken when interpreting the C_p ratio, because its computation does not involve the process mean. Unless the target value (i.e., process mean) is *centered* between the upper and lower specifications, the C_p ratio can be misleading. For example, suppose the

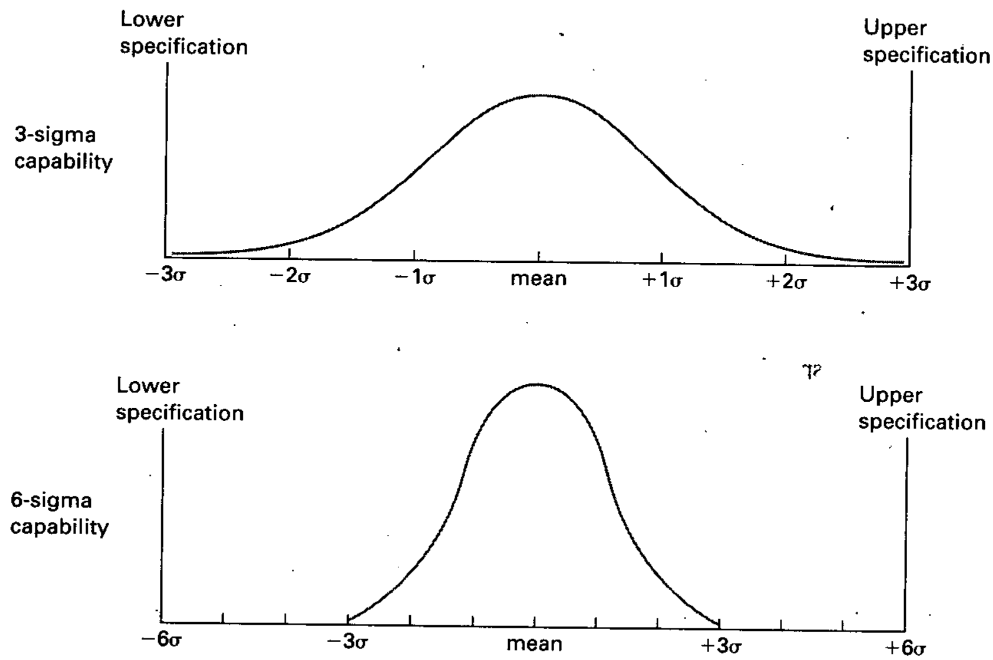


FIGURE 10.16
Three-sigma versus six-sigma capability

specifications are 10 and 11, and the standard deviation of the process is equal to 0.10. The C_p would seem to be very favorable:

$$\frac{11 - 10}{6(0.10)} = 1.67$$

However, suppose that the process mean is 12, with a standard deviation of 0.10; ±3 standard deviations would be 11.70 to 12.30, so it is very unlikely that *any* of the output would be within the specifications of 10 to 11!

There are situations in which the target value is not centered between the specifications, either intentionally, or unavoidably. In such instances, a more appropriate measure of process capability is the C_{pk} ratio, because it does take the process mean into account.

C_{pk}

If a process is not centered, a slightly different measure is used to compute its capability. This ratio is represented by the symbol C_{pk}. It is computed by finding the difference between each of the specification limits and the mean, identifying the smaller difference, and dividing that difference by three standard deviations of the process. Thus, C_{pk} is equal to the *smaller* of

$$\frac{\text{Upper specification} - \text{Process mean}}{3\sigma} \tag{10–11}$$

and

$$\frac{\text{Process mean} - \text{Lower specification}}{3\sigma}.$$

EXAMPLE 9

A process has a mean of 9.20 grams and a standard deviation of .30 gram. The lower specification limit is 7.50 grams and the upper specification limit is 10.50 grams. Compute C_{pk}.

SOLUTION

1. Compute the ratio for the lower specification:

$$\frac{\text{Process mean} - \text{Lower specification}}{3\sigma} = \frac{9.20 - 7.50}{3(.30)} = \frac{1.70}{.90} = 1.89$$

2. Compute the ratio for the upper specification:

$$\frac{\text{Upper specification} - \text{Process mean}}{3\sigma} = \frac{10.50 - 9.20}{3(.30)} = \frac{1.30}{.90} = 1.44$$

The *smaller* of the two ratios is 1.44, so this is the C_{pk}. Because the C_{pk} is more than 1.33, the process is capable.

You might be wondering why a process wouldn't be centered as a matter of course. One reason is that only a range of acceptable values, not a target value, may be specified. A more compelling reason is that the cost of nonconformance is greater for one specification limit than it is for nonconformance for the other specification limit. In that case, it would make sense to balance the cost per nonconforming unit multiplied by the probability of nonconformance, for the two specification limits. This would result in a noncentered process.

Improving Process Capability

Improving process capability requires changing the process target value and/or reducing the process variability that is inherent in a process. This might involve simplifying, standardizing, making the process mistake-proof, upgrading equipment, or automating. See Table 10.4 for examples.

TABLE 10.4
Process capability improvement

Method	Examples
Simplify	Eliminate steps, reduce the number of parts, use modular design
Standardize	Use standard parts, standard procedures
Make mistake-proof	Design parts that can only be assembled the correct way; have simple checks to verify a procedure has been performed correctly
Upgrade equipment	Replace wornout equipment; take advantage of technological improvements
Automate	Substitute automated processing for manual processing

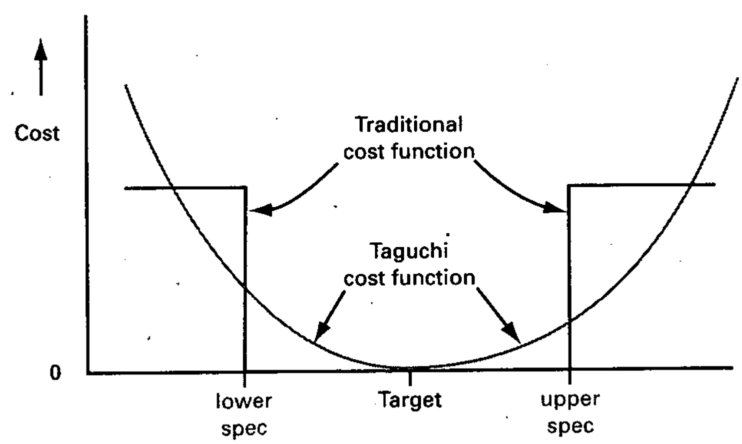


FIGURE 10.17
Taguchi and traditional views of the cost of poor quality

Taguchi Cost Function

Genichi Taguchi, a Japanese quality expert, holds a nontraditional view of what constitutes poor quality, and hence the cost of poor quality. The traditional view is that as long as output is within specifications, there is no cost. Taguchi believes that any deviation from the target value represents poor quality, and that the farther away from target a deviation is, the greater the cost. Figure 10.17 illustrates the two views. The implication for Taguchi is that reducing the variation inherent in a process (i.e., increasing its capability ratio) will result in lowering the cost of poor quality.

Barcodes Might Cut Drug Errors in Hospitals

NEWSCLIP

It's estimated that more than 7,000 hospital patients die each year because of drug errors, and many others suffer ill effects from being given the wrong drug or the wrong dosage. Some hospitals are using barcodes attached to patients' wristbands that allow hospital personnel who administer drugs to patients to electronically check to make sure the drug and dosage is appropriate. Before administering a drug, the doctor or nurse scans the barcode attached to the patient to see what drug is needed and when, and then the drug's barcode is scanned to verify that the medication is correct.

Source: Based on "Bar Codes Might Cut Drug Errors," *Rochester Democrat & Chronicle*, March 14, 2003, p. 9A.

Limitations of Capability Indexes

There are several risks of using a capability index:

1. The process may not be stable, in which case a capability index is meaningless.
2. The process output may not be normally distributed, in which case inferences about the fraction of output that isn't acceptable will be incorrect.
3. The process is not centered but the C_p index is used, giving a misleading result.

Operations Strategy

Quality is a major consideration for virtually all customers, so achieving and maintaining quality standards is of strategic importance to all business organizations. Quality assurance and product and service design are two vital links in the process. Organizations should continually seek to increase the capability of the processes they use, so that they can move from a position of using inspection or extensive use of control charts to achieve desired levels of quality to one where quality is built into products and processes, so that little or no efforts are needed to assure quality.

SUMMARY

This chapter describes inspection and statistical process control. Inspection means examining the output of a process to determine whether it is acceptable. Key issues in inspection include where to inspect in the process, how often to inspect, and whether to inspect on-site or in a laboratory.

Statistical process control focuses on detecting departures from randomness in a process. Two basic tools of process control are control charts and run tests. The general theory of control charts is discussed, and four types of control charts—two for variables and two for attributes—and two types of run tests are described in the chapter. The chapter ends with a discussion of process capability. Process capability studies are used to determine if the output of a process will satisfy specifications. They can provide valuable information for managers in terms of reducing costs and avoiding problems created by generating output that is not within specifications. Table 10.5 provides a summary of formulas.

KEY TERMS

assignable variation, 437
attributes, 439
c-chart, 445
control chart, 438
control limits, 438
inspection, 432
mean control chart, 439
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process capability, 451
process variability, 451
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random variation, 436
range control chart, 441
run, 448
run test, 447
specifications, 451
statistical process control, 435
Type I error, 438
Type II error, 439
variables, 439

TABLE 10.5
Summary of formulas

CONTROL CHARTS		
Name	**Symbol**	**Control Limits**
Mean	$\bar{x}$	$\bar{\bar{x}} \pm z\frac{\sigma}{\sqrt{n}}$ or $\bar{\bar{x}} \pm A_2\bar{R}$
Range	R	$UCL = D_4\bar{R}$, $LCL = D_3\bar{R}$
Fraction defective	p	$\bar{p} \pm z\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$
Number of defects	c	$\bar{c} \pm z\sqrt{\bar{c}}$

RUN TESTS				
	NUMBER OF RUNS			
Name	**Observed**	**Expected**	**Standard Deviation**	z
Median	r	$\frac{N}{2}+1$	$\sqrt{\frac{N-1}{4}}$	$\frac{r-[(N/2)+1]}{\sqrt{(N-1)/4}}$
Up/down	r	$\frac{2N-1}{3}$	$\sqrt{\frac{16N-29}{90}}$	$\frac{r-[(2N-1)/3]}{\sqrt{(16N-29)/90}}$

PROCESS CAPABILITY		
Name	**Symbol**	**Formula**
Capability index for a centered process	C_p	$\frac{\text{Specification width}}{6\sigma \text{ of process}}$
Capability index for a noncentered process	C_{pk}	Smaller of $\left\{ \frac{\text{Mean} - \text{Lower specification}}{3\sigma}, \frac{\text{Upper specification} - \text{Mean}}{3\sigma} \right.$

SOLVED PROBLEMS

Problem 1

Process distribution and sampling distribution. An industrial process that makes 3-foot sections of plastic pipe produces pipe with an average inside diameter of 1 inch and a standard deviation of .05 inch.

a. If you randomly select one piece of pipe, what is the probability that its inside diameter will exceed 1.02 inches, assuming the population is normal?

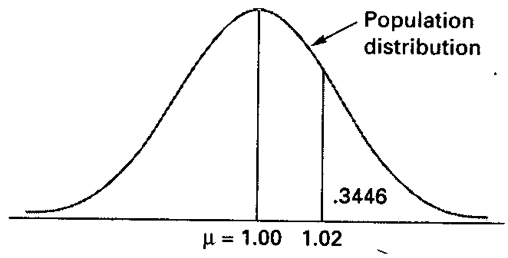
b. If you select a random sample of 25 pieces of pipe, what is the probability that the sample mean will exceed 1.02 inches?

Solution

$\mu = 1.00, \sigma = .05$

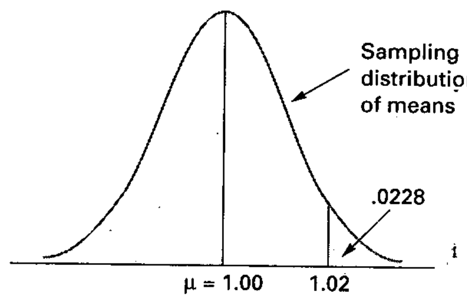
a. $z = \frac{x-\mu}{\sigma} = \frac{1.02 - 1.00}{.05} = 0.4$

Using Appendix B, Table A, $P(z > .4) = .5000 - .1554 = .3446$.



b. $z = \dfrac{\bar{x} - \mu}{\sigma/\sqrt{n}} = \dfrac{1.02 - 1.00}{.05/\sqrt{25}} = 2.00$

Using Appendix B, Table A, $P(z > 2.00) = .5000 - .4772 = .0228$



Problem 2

Control charts for means and ranges. Processing new accounts at a bank is intended to average 10 minutes each. Five samples of four observations each have been taken. Use the sample data in conjunction with Table 10.2 to construct upper and lower control limits for both a mean chart and a range chart. Do the results suggest that the process is in control?

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
	10.2	10.3	9.7	9.9	9.8
	9.9	9.8	9.9	10.3	10.2
	9.8	9.9	9.9	10.1	10.3
	10.1	10.4	10.1	10.5	9.7
Totals	40.0	40.4	39.6	40.8	40.0

Solution

a. Determine the mean and range of each sample.

$$\bar{x} = \frac{\sum x}{n}, \text{ Range} = \text{Largest} - \text{Smallest}$$

Sample	Mean	Range
1	40.0/4 = 10.0	10.2 − 9.8 = 0.4
2	40.4/4 = 10.1	10.4 − 9.8 = 0.6
3	39.6/4 = 9.9	10.1 − 9.7 = 0.4
4	40.8/4 = 10.2	10.5 − 9.9 = 0.6
5	40.0/4 = 10.0	10.3 − 9.7 = 0.6

b. Compute the average mean and average range:

$$\bar{\bar{x}} = \frac{10.0 + 10.1 + 9.9 + 10.2 + 10.0}{5} = \frac{50.2}{5} = 10.04$$

$$\bar{R} = \frac{0.4 + 0.6 + 0.4 + 0.6 + 0.6}{5} = \frac{2.6}{5} = 0.52$$

c. Obtain factors A_2, D_4, and D_3 from Table 10.2 for $n = 4$: $A_2 = 0.73$, $D_4 = 2.28$, $D_3 = 0$.

d. Compute upper and lower limits:

$$\text{UCL}_{\bar{x}} = \bar{\bar{x}} + A_2\bar{R} = 10.04 + 0.73(.52) = 10.42$$

$\text{LCL}_{\bar{x}} = \bar{\bar{x}} - A_2\bar{R} = 10.04 - 0.73(.52) = 9.66$

$\text{UCL}_R = D_4\bar{R} = 2.28(.52) = 1.19$

$\text{LCL}_R = D_3\bar{R} = 0(.52) = 0$

e. Verify that points are within limits.

The smallest sample mean is 9.9, and the largest is 10.2. Both are well within the control limits. Similarly, the largest sample range is .6, which is also within the control limits. Hence, the results suggest that the process is in control. Note, however, that for illustrative purposes, the number of samples is deliberately small; 20 or more samples would give a clearer indication of control limits and whether the process is in control.

Problem 3

Type I error (alpha risk). After several investigations of points outside control limits revealed nothing, a manager began to wonder about the probability of a Type I error for the control limits used ($z = 1.90$).

a. Determine the alpha risk P(Type 1 error) for this value of z.

b. What z would provide an alpha risk of about 2 percent?

Solution

a. Using Appendix B, Table A, find that the area under the curve between $z = 0$ and $z = +1.90$ is .4713. Therefore, the area (probability) of values *within* -1.90 to $+1.90$ is 2(.4713) = .9426, and the area *beyond* these values is 1 − .9426 = .0574. Hence, the alpha risk is 5.74%.

b. The alpha risk (Type I error probability) is always specified as an *area* in the tail(s) of a distribution. With control charts, you use two-sided control limits. Consequently, half of the risk lies in each tail. Hence, the area in the right tail is 1 percent, or .0100. This means that .4900 should be the area under the curve between $z = 0$ and the value of z you are looking for. The closest value is .4901 for $z = 2.33$. Thus, control limits based on $z = \pm 2.33$ provide an alpha risk of about 2 percent.

Problem 4

p-chart and *c-chart*. Using the appropriate control chart, determine two-sigma control limits for each case:

a. An inspector found an average of 3.9 scratches in the exterior paint of each of the automobiles being prepared for shipment to dealers.

b. Before shipping lawnmowers to dealers, an inspector attempts to start each mower and notes any that do not start on the first try. The lot size is 100 mowers, and an average of 4 did not start (4 percent).

Solution

The choice between these two types of control charts relates to whether *two* types of results can be counted (p-chart) or whether *only occurrences* can be counted (c-chart).

a. The inspector can only count the scratches that occurred, not the ones that did not occur. Consequently, a c-chart is appropriate. The sample average is 3.9 scratches per car. Two-sigma control limits are found using the formulas

$\text{UCL} = \bar{c} + z\sqrt{\bar{c}}$

$\text{LCL} = \bar{c} - z\sqrt{\bar{c}}$

where $\bar{c} = 3.9$ and $z = 2$. Thus,

$\text{UCL} = 3.9 + 2\sqrt{3.9} = 7.85$ scratches

$\text{LCL} = 3.9 - 2\sqrt{3.9} = -.05$, so the lower limit is 0 scratches

(Note: Round to zero only if the computed lower limit is negative.)

b. The inspector can count both the lawnmowers that started and those that did not start. Consequently, a p-chart is appropriate. Two-sigma control limits can be computed using the following:

$$\text{UCL} = \bar{p} + z\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$

$$\text{LCL} = \bar{p} + z\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$

where

$\bar{p} = .04$
$n = 100$
$z = 2$

Thus,

$$\text{UCL} = .04 + 2\sqrt{\frac{.04(96)}{100}} = .079$$

$$\text{LCL} = .04 - 2\sqrt{\frac{.04(.96)}{100}} = .001$$

Problem 5

Run tests. The number of defective items per sample for 11 samples is shown below. Determine if nonrandom patterns are present in the sequence.

	SAMPLE										
	1	2	3	4	5	6	7	8	9	10	11
Number of defectives	22	17	19	25	18	20	21	17	23	23	24

Solution

Since the median isn't given, it must be estimated from the sample data. To do this, array the data from low to high; the median is the middle value. (In this case, there are an odd number of values. For an even number of values, average the middle two to obtain the median.) Thus,

17 17 18 19 20 21 22 23 23 24 25
(5 below) ↑ (5 above)
median

The median is 21.

Next, code the observations using A/B and U/D:

Sample	A/B	Number of Defectives	U/D
1	A	22	—
2	B	17	D
3	B	19	U
4	A	25	U
5	B	18	D
6	B	20	U
7	tie	21	U
8	B	17	D
9	A	23	U
10	A	23	tie
11	A	24	U

Note that each test has tied values. How these are resolved can affect the number of observed runs. Suppose that you adhere to this rule: Assign letter (A or B, U or D) so that the resulting difference between the observed and expected number of runs is as large as possible. To accomplish this, it is necessary to initially ignore ties and count the runs to see whether there are too many or too few. Then return to the ties and make the assignments. The rationale for this rule is that it is a conservative method for retaining data; if you conclude that the data are random using this approach, you can be reasonably confident that the method has not "created" randomness. With this in mind, assign a B to sample 7 since the expected number of runs is

$$E(r)_{\text{med}} = N/2 + 1 = 11/2 + 1 = 6.5$$

and the difference between the resulting number of runs, 5, and 6.5 is greater than between 6.5 and 7 (which occurs if A is used instead of B). Similarly, in the up/down test, a U for sample 10 produces 6 runs, whereas a D produces 8 runs. Since the expected number of runs is

$E(r)_{u/d} = (2N - 1) \div 3 = (22 - 1) \div 3 = 7$

it makes no difference which one is used: both yield a difference of 1. For the sake of illustration, a D is assigned.

The computations for the two tests are summarized below. Each test has a z value that is within the range of ± 2.00. Because neither test reveals nonrandomness, you may conclude that the data are random.

	Runs Observed	$E(r)$	σ_r	z	Conclude
Median	5	6.5	1.58	−0.95	Random
Up/down	8	7.0	1.28	0.78	Random

DISCUSSION AND REVIEW QUESTIONS

1. List the steps in the control process.
2. What are the key concepts that underlie the construction and interpretation of control charts?
3. What is the purpose of a control chart?
4. Why is order of observation important in process control?
5. Briefly explain the purpose of each of these control charts:
   a. x-bar
   b. Range
   c. p-chart
   d. c-chart
6. What is a run? How are run charts useful in process control?
7. If all observations are within control limits, does that guarantee that the process is random? Explain.
8. Why is it usually desirable to use both a median run test and an up/down run test on the same data?
9. If both run tests are used, and neither reveals nonrandomness, does that prove that the process is random? Explain.
10. Define and contrast control limits, specifications, and process variability.
11. A customer has recently tightened the specs for a part your company supplies. The specs are now much tighter than the machine being used for the job is capable of. Briefly identify alternatives you might consider to resolve this problem. (See Figure 10.15C.)
12. A new order has come into your department. The capability of the machine used for this type of work will enable virtually all of the output to be well within the specs. (See Figure 10.15B.)
    a. What benefits might be derived from this situation?
    b. What alternatives might be considered by the manager?
13. Answer these questions about inspection:
    a. What level of inspection is optimal?
    b. What factors guide the decision of how much to inspect?
    c. What are the main considerations in choosing between centralized inspection and on-site inspection?
    d. What points are potential candidates for inspection?
14. What two basic assumptions must be satisfied in order to use a process capability index?
15. How important is it for managers to maintain and promote ethical behavior in dealing with quality issues? Does your answer depend on the product or service involved?
16. Classify each of the following as either a Type I error or a Type II error:
    a. Putting an innocent person in jail.
    b. Releasing a guilty person from jail.
    c. Eating (or not eating) a cookie that fell on the floor.
    d. Not seeing a doctor as soon as possible after ingesting poison.

TAKING STOCK

1. What trade-offs are involved in each of these decisions?
   a. Deciding whether to use two-sigma or three-sigma control limits.
   b. Choosing between a large sample size and a smaller sample size.
   c. Trying to increase the capability of a process that is barely capable.

2. Who needs to be involved in setting quality standards?
3. Name several ways that technology has had an impact on quality control.

CRITICAL THINKING EXERCISE

Analysis of the output of a process has suggested that the variability is nonrandom on several occasions recently. However, each time an investigation has not revealed any assignable causes. What are some of the possible explanations for not finding any causes? What should the manager do?

PROBLEMS

1. Specifications for a part for a DVD player state that the part should weigh between 24 and 25 ounces. The process that produces the parts yields a mean of 24.5 ounces and a standard deviation of .2 ounce. The distribution of output is normal.
   a. What percentage of parts will not meet the weight specs?
   b. Within what values will 95.44 percent of sample means of this process fall, if samples of $n = 16$ are taken and the process is in control (random)?
2. An automatic filling machine is used to fill 1-liter bottles of cola. The machine's output is approximately normal with a mean of 1.0 liter and a standard deviation of .01 liter. Output is monitored using means of samples of 25 observations.
   a. Determine upper and lower control limits that will include roughly 97 percent of the sample means when the process is in control.
   b. Given these sample means: 1.005, 1.001, .998, 1.002, .995, and .999, is the process in control?
3. Checkout time at a supermarket is monitored using a mean and a range chart. Six samples of $n = 20$ observations have been obtained and the sample means and ranges computed:

Sample	Mean	Range
1	3.06	0.42
2	3.15	0.50
3	3.11	0.41
4	3.13	0.46
5	3.06	0.46
6	3.09	0.45

   a. Using the factors in Table 10.2, determine upper and lower limits for mean and range charts.
   b. Is the process in control?
4. Computer upgrades have a nominal time of 80 minutes. Samples of five observations each have been taken, and the results are as listed. Using factors from Table 10.2, determine upper and lower control limits for mean and range charts, and decide if the process is in control.

SAMPLE					
1	2	3	4	5	6
79.2	80.5	79.6	78.9	80.5	79.7
78.8	78.7	79.6	79.4	79.6	80.6
80.0	81.0	80.4	79.7	80.4	80.5
78.4	80.4	80.3	79.4	80.8	80.0
81.0	80.1	80.8	80.6	78.8	81.1

5. Using samples of 200 credit card statements, an auditor found the following:

Sample	1	2	3	4
Number of errors	4	2	5	9

   a. Determine the fraction defective in each sample.
   b. If the true fraction defective for this process is unknown, what is your estimate of it?
   c. What is your estimate of the mean and standard deviation of the sampling distribution of fractions defective for samples of this size?
   d. What control limits would give an alpha risk of .03 for this process?
   e. What alpha risk would control limits of .047 and .003 provide?
   f. Using control limits of .047 and .003, is the process in control?
   g. Suppose that the long-term fraction defective of the process is known to be 2 percent. What are the values of the mean and standard deviation of the sampling distribution?

h. Construct a control chart for the process, assuming a fraction defective of 2 percent, using two-sigma control limits. Is the process in control?

6. A medical facility does MRIs for sports injuries. Occasionally a test yields inconclusive results and must be repeated. Using the following sample data and $n = 200$, determine the upper and lower control limits for the fraction of retests using two-sigma limits. Is the process in control? If not, eliminate any values that are outside the limits and compute revised limits.

	SAMPLE												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Number of retests ...	1	2	2	0	2	1	2	0	2	7	3	2	1

7. The postmaster of a small western town receives a certain number of complaints each day about mail delivery. Determine three-sigma control limits using the following data. Is the process in control?

	DAY													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Number of complaints	4	10	14	8	9	6	5	12	13	7	6	4	2	10

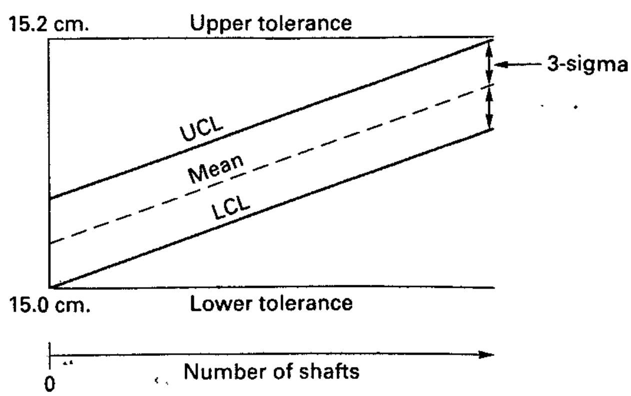
8. Given the following data for the number of defects per spool of cable, using three-sigma limits, is the process in control?

	OBSERVATION													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Number of defects	2	3	1	0	1	3	2	0	2	1	3	1	2	0

9. After a number of complaints about its directory assistance, a telephone company examined samples of calls to determine the frequency of wrong numbers given to callers. Each sample consisted of 100 calls. Determine 95 percent limits. Is the process stable (i.e., in control)? Explain.

	SAMPLE															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Number of errors	5	3	5	7	4	6	8	4	5	9	3	4	5	6	6	7

10. Specifications for a metal shaft are much wider than the machine used to make the shafts is capable of. Consequently, the decision has been made to allow the cutting tool to wear a certain amount before replacement. The tool wears at the rate of .004 centimeter per piece. The process has a natural variation, σ, of .01 centimeter and is normally distributed. Specifications are 15.0 to 15.2 centimeters, and $n = 1$. For three-sigma limits, how many shafts can the process turn out before tool replacement becomes necessary? (See diagram.)



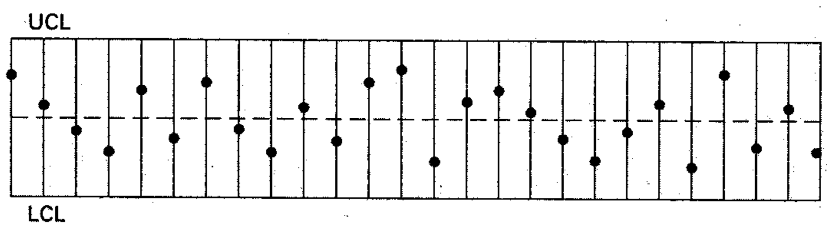
11. Specifications for the computer upgrades in Problem 4 are 78 minutes and 81 minutes. Based on the data given in the problem, are the specifications being met? Estimate the percentage of process output that can be expected to fall within the specifications.

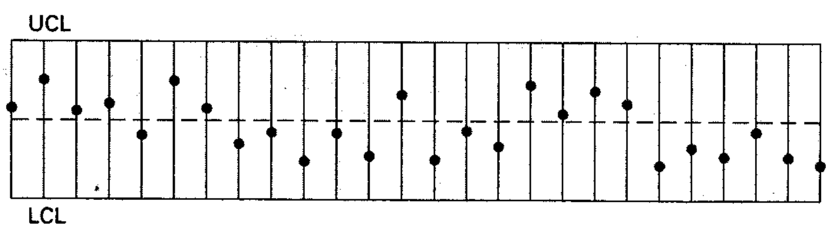
12. The time needed for checking in at a hotel is to be investigated. Historically, the process has had a standard deviation equal to .146. The means of 39 samples of $n = 14$ are

Sample	Mean	Sample	Mean	Sample	Mean
1	3.86	14	3.81	27	3.81
2	3.90	15	3.83	28	3.86
3	3.83	16	3.86	29	3.98
4	3.81	17	3.82	30	3.96
5	3.84	18	3.86	31	3.88
6	3.83	19	3.84	32	3.76
7	3.87	20	3.87	33	3.83
8	3.88	21	3.84	34	3.77
9	3.84	22	3.82	35	3.86
10	3.80	23	3.89	36	3.80
11	3.88	24	3.86	37	3.84
12	3.86	25	3.88	38	3.79
13	3.88	26	3.90	39	3.85

a. Construct an $\bar{x}$-chart for this process with three-sigma limits. Is the process in control?
b. Analyze the data using a median run test and an up/down run test. What can you conclude?

13. For each of the accompanying control charts, analyze the data using both median and up/down run tests with $z = \pm 1.96$ limits. Are nonrandom variations present? Assume the center line is the long-term median.

A.


B.


14. Analyze the data in the problems listed below using median and up/down run tests with $z = \pm 2$.
a. Problem 8.
b. Problem 7.

15. Use both types of run tests to analyze the daily expense voucher listed. Assume a median of $31.

Day	Amount	Day	Amount	Day	Amount
1	$27.69	10	$32.51	19	$29.10
2	28.13	11	27.98	20	25.19
3	33.02	12	31.25	21	28.60
4	30.31	13	33.98	22	20.02
5	31.59	14	25.56	23	26.67
6	33.64	15	24.46	24	36.40
7	34.73	16	29.65	25	32.07
8	35.09	17	31.08	26	44.10
9	33.39	18	33.03	27	41.44

28 .... 29.62	39 .... 35.80	50 .... 29.14
29 .... 30.12	40 .... 32.23	51 .... 37.78
30 .... 26.39	41 .... 26.76	52 .... 34.16
31 .... 40.54	42 .... 30.51	53 .... 38.28
32 .... 36.31	43 .... 29.35	54 .... 29.49
33 .... 27.14	44 .... 24.09	55 .... 30.81
34 .... 30.38	45 .... 22.45	56 .... 30.60
35 .... 31.96	46 .... 25.16	57 .... 34.46
36 .... 32.03	47 .... 26.11	58 .... 35.10
37 .... 34.40	48 .... 29.84	59 .... 31.76
38 .... 25.67	49 .... 31.75	60 .... 34.90

16. A company has just negotiated a contract to produce a part for another firm. In the process of manufacturing the part, the inside diameter of successive parts becomes smaller and smaller as the cutting tool wears. However, the specs are so wide relative to machine capabilities that it is possible to set the diameter initially at a large value and let the process run for a while before replacing the cutting tool.

    The inside diameter decreases at an average rate of .001 cm per part, and the process has a standard deviation of .01 cm. The variability is approximately normal. Assuming three-sigma control limits, how frequently must the tool be replaced if the process specs are 3 cm and 3.5 cm, and the initial setting of the UCL is at the upper spec? Use $n = 1$.

17. (Refer to Solved Problem 2.) Suppose the process specs are 9.65 and 10.35 minutes. Based on the data given, does it appear that the specs are being met? If not, what should one look for?

18. A production process consists of a three-step operation. The scrap rate is 10 percent for the first step and 6 percent for the other two steps.
    a. If the desired daily output is 450 units, how many units must be started to allow for loss due to scrap?
    b. If the scrap rate for each step could be cut in half, how many units would this save in terms of the scrap allowance?
    c. If the scrap represents a cost of $10 per unit, how much is it costing the company per day for the original scrap rate?

19. (Refer to the data in Example 5.) Two additional observations have been taken. The first resulted in three defects, and the second had four defects. Using the set of 20 observations, perform run tests on the data. What can you conclude about the data?

20. A teller at a drive-up window at a bank had the following service times (in minutes) for 20 randomly selected customers:

SAMPLE			
1	2	3	4
4.5	4.6	4.5	4.7
4.2	4.5	4.6	4.6
4.2	4.4	4.4	4.8
4.3	4.7	4.4	4.5
4.3	4.3	4.6	4.9

a. Determine the mean of each sample.
b. If the process parameters are unknown, estimate its mean and standard deviation.
c. Estimate the mean and standard deviation of the sampling distribution.
d. What would three-sigma control limits for the process be? What alpha risk would they provide?
e. What alpha risk would control limits of 4.14 and 4.86 provide?
f. Using limits of 4.14 and 4.86, are any sample means beyond the control limits? If so, which one(s)?
g. Construct control charts for means and ranges using Table 10.2. Are any samples beyond the control limits? If so, which one(s)?
h. Explain why the control limits are different for means in parts *d* and *g*.
i. If the process has a known mean of 4.4 and a known standard deviation of .18, what would three-sigma control limits be for a mean chart? Are any sample means beyond the control limits? If so, which one(s)?

21. A process that produces computer chips has a mean of .03 defective chip and a standard deviation of .003 chip. The allowable variation is from .02 to .04 defective.
    a. Compute the capability ratio for the process.
    b. Is the process capable?

22. Given the following list of machines, the standard deviation for each, and specifications for a job that may be processed on that machine, determine which machines are capable of performing the given jobs.

Machine	Standard Deviation (in.)	Job Specification (±in.)
001	0.02	0.05
002	0.04	0.07
003	0.10	0.18
004	0.05	0.15
005	0.01	0.04

23. Suppose your manager presents you with the following information about machines that could be used for a job, and wants your recommendation on which one to choose. The specification width is .48 mm. In this instance, you can narrow the set of choices, but you probably wouldn't make a recommendation without an additional piece of information. Explain the logic of the last statement.

Machine	Cost per Unit ($)	Standard Deviation (mm)
A	20	.059
B	12	.060
C	11	.063
D	10	.061

24. Each of the processes listed is noncentered with respect to the specifications for that process. Compute the appropriate capability index for each, and decide if the process is capable.

Process	Mean	Standard Deviation	Lower Spec	Upper Spec
H	15.0	0.32	14.1	16.0
K	33.0	1.00	30.0	36.5
T	18.5	0.40	16.5	20.1

25. An appliance manufacturer wants to contract with a repair shop to handle authorized repairs in Indianapolis. The company has set an acceptable range of repair time of 50 minutes to 90 minutes. Two firms have submitted bids for the work. In test trials, one firm had a mean repair time of 74 minutes with a standard deviation of 4.0 minutes and the other firm had a mean repair time of 72 minutes with a standard deviation of 5.1 minutes. Which firm would you choose? Why?

26. As part of an insurance company's training program, participants learn how to conduct an analysis of clients' insurability. The goal is to have participants achieve a time in the range of 30 to 45 minutes. Test results for three participants were: Armand, a mean of 38 minutes and a standard deviation of 3 minutes; Jerry, a mean of 37 minutes and a standard deviation of 2.5 minutes; and Melissa, a mean of 37.5 minutes and a standard deviation of 1.8 minutes.
    a. Which of the participants would you judge to be capable? Explain.
    b. Can the value of the C_{pk} exceed the value of C_p for a given participant? Explain.

Toys, Inc. — CASE

TOYS, Inc., is a 20-year-old company engaged in the manufacture and sale of toys and board games. The company has built a reputation on quality and innovation. Although the company is one of the leaders in its field, sales have leveled off in recent years. For the most recent six-month period, sales actually declined compared with the same period last year. The production manager, Ed Murphy, attributed the lack of sales growth to "the

(continued)

(concluded)

economy." He was prompted to undertake a number of belt-tightening moves that included cuts in production costs and layoffs in the design and product development departments. Although profits are still flat, he believes that within the next six months, the results of his decisions will be reflected in increased profits.

The vice president of sales, Joe Martin, has been concerned with customer complaints about the company's REALISTIC™ line of working-model factories, farms, and service stations. The moving parts on certain models have become disengaged and fail to operate or operate eratically. His assistant, Keith McNally, has proposed a trade-in program by which customers could replace malfunctioning models with new ones. McNally believes that this will demonstrate goodwill and appease dissatisfied customers. He also proposes rebuilding the trade-ins and selling them at discounted prices in the company's retail outlet store. He doesn't think that this will take away from sales of new models. Under McNally's program, no new staff would be needed. Regular workers would perform needed repairs during periods of seasonal slowdowns, thus keeping production level.

When Steve Bukowski, a production assistant, heard Keith's proposal, he said that a better option would be to increase inspection of finished models before they were shipped. "With 100 percent inspection, we can weed out any defective models and avoid the problem entirely."

Take the role of a consultant who has been called in for advice by the company president, Marybeth Corbella. What do you recommend?

Tiger Tools

CASE

Tiger Tools, a division of Drillmore Industries, was about to launch a new product. Production Manager Michelle York asked her assistant, Jim Peterson, to check the capability of the oven used in the process. Jim obtained 18 random samples of 20 pieces each. The results of those samples are shown in the following table. After he analyzed the data, he concluded that the process was not capable based on a specification width of 1.44 cm.

Michelle was quite disappointed when she heard this. She had hoped that with the introduction of the new product her operation could run close to full capacity and regain some of its lost luster. The company had a freeze on capital expenditures of more than $10,000, and a replacement oven would cost many times that amount. Jim Peterson worked with the oven crew to see if perhaps different settings could produce the desired results, but they were unable to achieve any meaningful improvements.

Sample	Mean	Range
1	45.01	.85
2	44.99	.89
3	45.02	.86
4	45.00	.91
5	45.04	.87
6	44.98	.90
7	44.91	.86
8	45.04	.89
9	45.00	.85
10	44.97	.91
11	45.11	.84
12	44.96	.87
13	45.00	.86
14	44.92	.89
15	45.06	.87
16	44.94	.86
17	45.00	.85
18	45.03	.88

Still not ready to concede, Michelle contacted one of her former professors and explained the problem. The professor suggested obtaining another set of samples, this time using a smaller sample size and taking more samples. Michelle then conferred with Jim and they agreed that he would take 27 samples of five observations each. The results are shown in the following table.

Sample	Mean	Range
1	44.96	.42
2	44.98	.39
3	44.96	.41
4	44.97	.37
5	45.02	.39
6	45.03	.40
7	45.04	.39
8	45.02	.42
9	45.08	.38
10	45.12	.40
11	45.07	.41
12	45.02	.38
13	45.01	.41
14	44.98	.40
15	45.00	.39
16	44.95	.41
17	44.94	.43
18	44.94	.40
19	44.87	.38

(continued)

(concluded)

20	44.95	.41
21	44.93	.39
22	44.96	.41
23	44.99	.40
24	45.00	.44
25	45.03	.42
26	45.04	.38
27	45.03	.40

Consider the following questions, and then write a brief report to Michelle summarizing your findings.

1. How did Jim conclude that the process was not capable based on his first set of samples? (Hint: Estimate the process standard deviation, σ, using $A_2\bar{R} \approx 3\frac{\sigma}{\sqrt{n}}$.)
2. Does the second set of samples show anything that the first set didn't? Explain what and why.
3. Assuming the problem can be found and corrected, what impact do you think this would have on the capability of the process? Compute the potential process capability.
4. If small samples can reveal something that large samples might not, why not just take small samples in every situation?

In the Chips at Jays

OPERATIONS TOUR

Neil Steinberg

www.jaysfoods.com

A potato chip is a delicate thing. Fragile. A pound of pressure will crush it. So when you're moving 250 tons of chips through your plant, as they do every day at Jays Foods, you need to have a system.

"You don't buy potato crumbs, you buy potato chips," said Tom Howe, CEO and co-owner of the Chicago company, at 99th and Cottage Grove. Jays makes 125 different types and brands of chips and several hundred varieties of popcorn, puffs, twists, pretzels and assorted bagged munchies.

Jays combats the tendency of potato chips to crush into flinders with a variety of conveyor belts, radial filling chutes and gently vibrating slides, where masses of chips, a yard deep, are gradually massaged forward, the outer layer of chips shearing away like the face of a glacier.

The raw material is far easier to handle. An entire semi-trailer of sturdy North Dakota "chipping" potatoes can be emptied in a matter of minutes, by backing the trailer onto a hydraulic lift, tilting it 45 degrees and letting the potatoes—grown for their thin skins and low moisture—tumble out.

About a dozen semi-trailers' worth of potatoes arrive every day. The potatoes are immediately separated into big and small sizes for a purpose both reasonable and extraordinary: Big potatoes make big chips that go into large bags; small potatoes make small chips for lunch-size bags.

"Nobody wants to open a small bag and find three big potato chips in it," Howe said.

Computers keep track of everything, shunting potatoes to 15,000-pound holding bins. Each bin feeds into a pipe containing a turning screw—a version of the ancient Archimedes screw used to pump water—that moves the potatoes from the bin to conveyor belts, to where they are washed and skinned—the skin scrubbed off by metal bristle brushes.

No machine can detect if a potato is rotten inside. So a pair of human inspectors reach into the passing brown parade and give the potatoes a quick squeeze. Occasionally, they snatch one and slice it open, usually revealing black areas of rot, a skill they attribute to experience.

"I *know*," said Alicia Jimenez, asked to explain what about a potato tips her off to slice it open and find rot.

The naked potatoes are sent into high-speed chippers—spinning brass rings, each with eight blades inside, straight blades for straight chips, ripple blades for ripple chips.

The blades cut the potatoes, but the potatoes take their revenge. Every three hours the blades are dulled and the line must be stopped so the old rings can be replaced by new rings with sharpened blades.

The sheer quantity of slicing spews big foamy banks of starch from either side of the chipper, which calls to mind a washing machine gone berserk.

Potato chips account for about 55 percent of Jays' business.

The raw chips spend three minutes cooking in hot corn oil, which is constantly circulated and filtered. Then they are salted, and flavorings—barbecue, for instance, or sour cream and onion—are added.

After the chips are fried, there is another quality check, in which workers pluck burned and deformed chips out of the masses passing by. The chips are conveyed on a link grid, wide enough to let broken chips fall through.

The chips also are laser-inspected, rushing, in a single layer, over a complex device called an Opti-Sort Scanner. Chips with dark spots or holes are detected by a laser, which instructs one of 82 small tubes to fire a puff of air that knocks the substandard chip off the line, into a discard bin.

The discards—about 3 percent of production—are gathered up and used: Starch is drawn out and sold to cornstarch makers; the rest goes to hog feed. Just as the stockyards were said to use every part of the pig but the squeal, at Jays every part of the potato is used but the rich, earthy smell.

(continued)

(concluded)

Jays even tried to sell burnt chips to the public once, about 20 years ago. "Consumers kept telling us they liked the brown chips," said Len Japp Jr., recalling the "Brownies" variety. "It went over like a lead balloon." Japp and his father, now 93 and honorary chairman of the board, sold the company to Borden in 1986. "They almost ruined it," Howe said, citing a slump in product quality and neglect of the Jays distribution system. "They lost the connection with the consumer."

By 1994, Jays was on the rocks and the Japps, allied with Howe, bought the company back. "Not too many people have a second chance in life," said Japp, whose children are in the company.

Getting the chips in the bags is another challenge: You can't just fill up bags and seal them; the chips would be smashed. Rather, a conveyor pours chips—gently—onto the central hub of a large, wheel-like device, where the chips scatter into 15 buckets that are, basically, scales. A computer monitors the weight of each bucket and opens up the exact combination that, in this case, will fill a 14-ounce bag. The bags are packed into boxes that read: "HANDLE LIKE EGGS."

While not exactly perishable, potato chips do have a shelf life of about eight weeks, only one day of which is spent at the plant.

"Potatoes that are in this morning will be in our branches tomorrow morning, ready to hit the streets," Howe said. Jays is still a regional brand, sold in Illinois, Indiana, Michigan, Wisconsin and Missouri. But business has grown 50 percent in the past two years.

"We connect to people's lifestyle," Howe said. "People treat themselves with Jays. We're in the fun food business."

Source: "In the Chips," Neil Steinberg, *Chicago Sun-Times,* December 26, 1997.

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Supplement to

CHAPTER 10

Acceptance Sampling

LEARNING OBJECTIVES

After completing this supplement, you should be able to:

1 Explain the purpose of acceptance sampling.

2 Contrast acceptance sampling and process control.

3 Compare and contrast single- and multiple-sampling plans.

4 Determine the average outgoing quality of inspected lots.

SUPPLEMENT OUTLINE

INTRODUCTION

acceptance sampling Form of inspection applied to lots or batches of items before or after a process, to judge conformance with predetermined standards.

Acceptance sampling is a form of inspection that is applied to lots or batches of items either before or after a process instead of during the process. In the majority of cases, the lots represent incoming purchased items or final products awaiting shipment to warehouses or customers. The purpose of acceptance sampling is to decide whether a lot satisfies predetermined standards. Lots that satisfy these standards are *passed* or *accepted;* those that do not are *rejected.* Rejected lots may be subjected to 100 percent inspection, or in the case of purchased goods, they may be returned to the supplier for credit or replacement (especially if destructive testing is involved).

Acceptance sampling procedures are most useful when one or more of the following conditions exist:

1. A large number of items must be processed in a short time.
2. The cost consequences of passing defectives are low.
3. Destructive testing is required.
4. Fatigue or boredom caused by inspecting large numbers of items leads to inspection errors.

Acceptance sampling procedures can be applied to both attribute (counts) and variable (measurements) inspection. However, inspection of attributes is perhaps more widely used, so for purposes of illustration, the discussion here focuses exclusively on attribute sampling plans.

SAMPLING PLANS

A key element of acceptance sampling is the sampling plan. **Sampling plans** specify the lot size, N; the sample size, n; the number of samples to be taken; and the acceptance/rejection criteria. A variety of sampling plans can be used. Some plans call for selection of a single sample, and others call for two or more samples, depending on the nature of the plan. The following paragraphs briefly describe some of the different kinds of plans.

sampling plans Plans that specify lot size, sample size, number of samples, and acceptance/rejection criteria.

Single-Sampling Plan

In the single plan, one random sample is drawn from each lot, and every item in the sample is examined and classified as either "good" or "defective." If any sample contains more than a specified number of defectives, c, that lot is rejected.

Double-Sampling Plan

A double-sampling plan allows for the opportunity to take a second sample if the results of the initial sample are inconclusive. For example, if the quality of the initial sample is high, the lot can be accepted without need for a second sample. If the quality in the initial sample is poor, sampling also can be terminated and the lot rejected. For results between those two cases, a second sample is then taken and the items inspected, after which the lot is either accepted or rejected on the basis of the evidence obtained from both samples. A double-sampling plan specifies the lot size, the size of the initial sample, accept/reject criteria for the initial sample, the size of the second sample, and a single acceptance number for the combined samples.

With a double-sampling plan, two values are specified for the number of defective items, a lower level, c_1, and an upper level, c_2. For instance, the lower level might be two defectives and the upper level might be five defectives. Using those values as decision rules, the first sample is taken. If the number of defective items in the first sample is less than or equal to the lower value (i.e., c_1), the lot is judged to be good and sampling is terminated. Conversely, if the number of defectives exceeds the upper value (i.e., c_2), the lot is rejected. If the number of defectives falls somewhere in between, a second sample is taken and the number of defectives in both samples is compared to a third value, c_3. For example, c_3 might be six. If the combined number of defectives does not exceed that value, the lot is accepted; otherwise, the lot is rejected.

Multiple-Sampling Plan

A multiple-sampling plan is similar to a double-sampling plan except that more than two samples may be required. A sampling plan will specify each sample size and two limits for each sample. The values increase with the number of samples. If, for any sample, the cumulative number of defectives found (i.e., those in the present sample plus those found in all previous samples) exceeds the upper limit specified for that sample, sampling is terminated and the lot is rejected. If the cumulative number of defectives is less than or equal to the lower limit, sampling is terminated and the lot is passed. If the number is between the two limits, another sample is taken. The process continues until the lot is either accepted or rejected.

Choosing a Plan

The cost and time required for inspection often dictate the kind of sampling plan used. The two primary considerations are the number of samples needed and the total number of observations required. Single-sampling plans involve only a single sample, but the sample size is large relative to the total number of observations taken under double- or multiple-sampling plans. Where the cost to obtain a sample is relatively high compared with the cost to analyze the observations, a single-sampling plan is more desirable. For instance, if a sample of moon soil is needed, clearly the cost of returning for a second or third sample far outweighs the cost of analyzing a single large sample. Conversely, where item inspection costs are relatively high, such as destructive testing, it may be better to use double or multiple sampling because the average number of items inspected per lot will be lower. This stems from the fact that a very good or very poor lot quality will often show up initially, and sampling can be terminated.

OPERATING CHARACTERISTIC CURVE

operating characteristic (OC) curve Probability curve that shows the probabilities of accepting lots with various fractions defective.

An important feature of a sampling plan is how it discriminates between lots of high and low quality. The ability of a sampling plan to discriminate is described by its **operating characteristic (OC) curve.** A typical curve for a single-sampling plan is shown in Figure 10S.1. The curve shows the probability that a given sampling plan will result in lots with various *fractions defective* being accepted. For example, the graph shows that a lot with 3 percent of defectives (a fraction defective of .03) would have a probability of about .90 of being accepted (and a probability of 1.00 − .90 = .10 of being rejected). Note the downward relationship: As lot quality decreases, the probability of acceptance decreases, although the relationship is not linear.

A sampling plan does not provide perfect discrimination between good and bad lots; some low-quality lots will invariably be accepted, and some lots with very good quality will invariably be rejected. Even lots containing more than 20 percent defectives still have some probability of acceptance; whereas lots with as few as 3 percent defectives have some chance of rejection.

The degree to which a sampling plan discriminates between good and bad lots is a function of the steepness of the graph's OC curve: the steeper the curve, the more discriminating the sampling plan. (See Figure 10S.2.) Note the curve for an ideal plan (i.e., one that can discriminate

FIGURE 10S.1

A typical OC curve for proportions

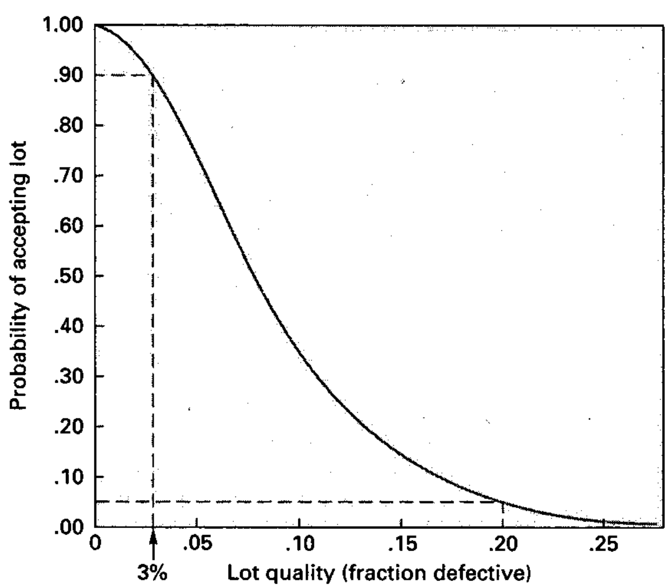
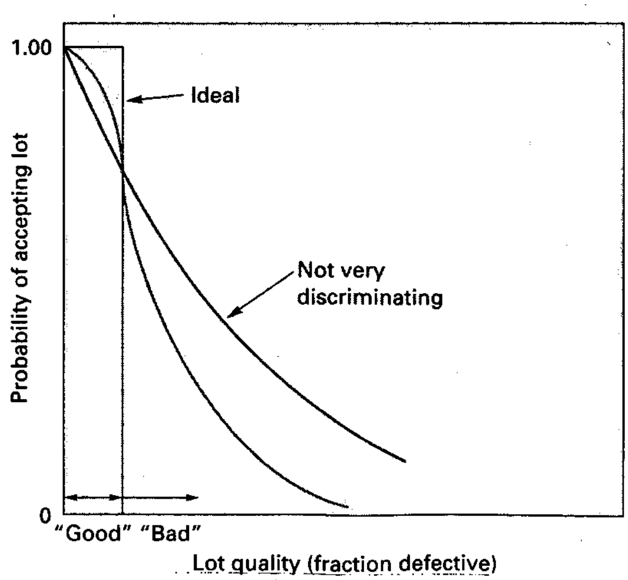


FIGURE 10S.2

The steeper the OC curve, the more discriminating the sampling plan



perfectly between good and bad lots). To achieve that, you need to inspect 100 percent of each lot. Obviously, if you are going to do that, theoretically, *all* of the defectives can be eliminated (although errors and boredom might result in a few defectives remaining). However, the point is that 100 percent inspection provides a perspective from which to view the OC curves of other sampling plans.

Be aware that the cost and time needed to conduct 100 percent inspection often rule out 100 percent inspection, as does destructive testing, leaving acceptance sampling as the only viable alternative.

For these reasons, buyers ("consumers") are generally willing to accept lots that contain small percentages of defective items as "good," especially if the cost related to a few defects is low. Often this percentage is in the neighborhood of 1 percent to 2 percent defective. This figure is known as the **acceptable quality level (AQL).**

Because of the inability of random sampling to clearly identify lots that contain more than this specified percentage of defective items, consumers recognize that some lots that actually contain more will be accepted. However, there is usually an upper limit on the percentage of defective items that a consumer is willing to tolerate in accepted lots. This is known as the **lot tolerance percent defective (LTPD).** Thus, consumers want quality equal to or better than the AQL, and are willing to live with some lots with quality as poor as the LTPD, but they prefer not to accept any lots with a defective percentage that exceeds the LTPD. The probability that a lot containing defectives exceeding the LTPD will be accepted is known as the **consumer's risk,** or *beta* (β), or the probability of making a *Type II error.* The probability that a lot containing the acceptable quality level will be rejected is known as the **producer's risk,** *alpha* (α), or the probability of making a *Type I error.* Many sampling plans are designed to have a producer's risk of 5 percent and a consumer's risk of 10 percent, although other combinations are also used. It is possible by trial and error to design a plan that will provide selected values for alpha and beta given the AQL and the LTPD. However, standard references such as the government MIL-STD tables are widely used to obtain sample sizes and acceptance criteria for sampling plans. Figure 10S.3 illustrates an OC curve with the AQL, LTPD, producer's risk, and consumer's risk.

acceptable quality level (AQL) The percentage level of defects at which consumers are willing to accept lots as "good."

lot tolerance percent defective (LTPD) The upper limit on the percentage of defects that a consumer is willing to accept.

consumer's risk The probability that a lot containing defects exceeding the LTPD will be accepted.

producer's risk The probability that a lot containing the acceptable quality level will be rejected.

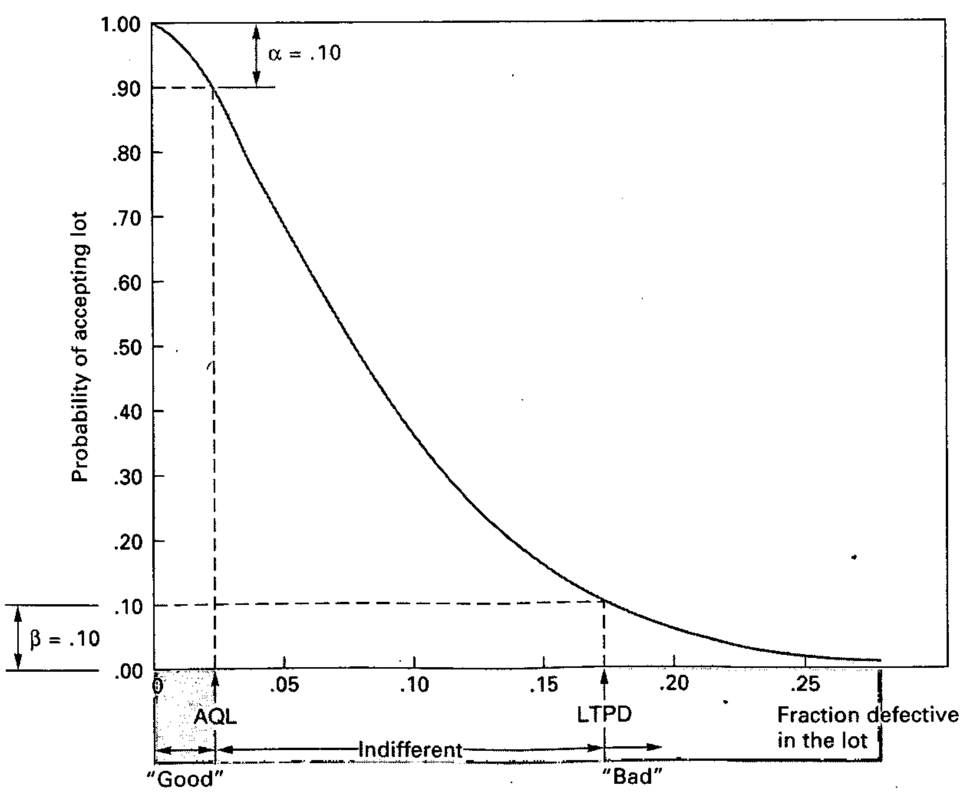


FIGURE 10S.3

The AQL indicates good lots, and the LTPD indicates bad lots

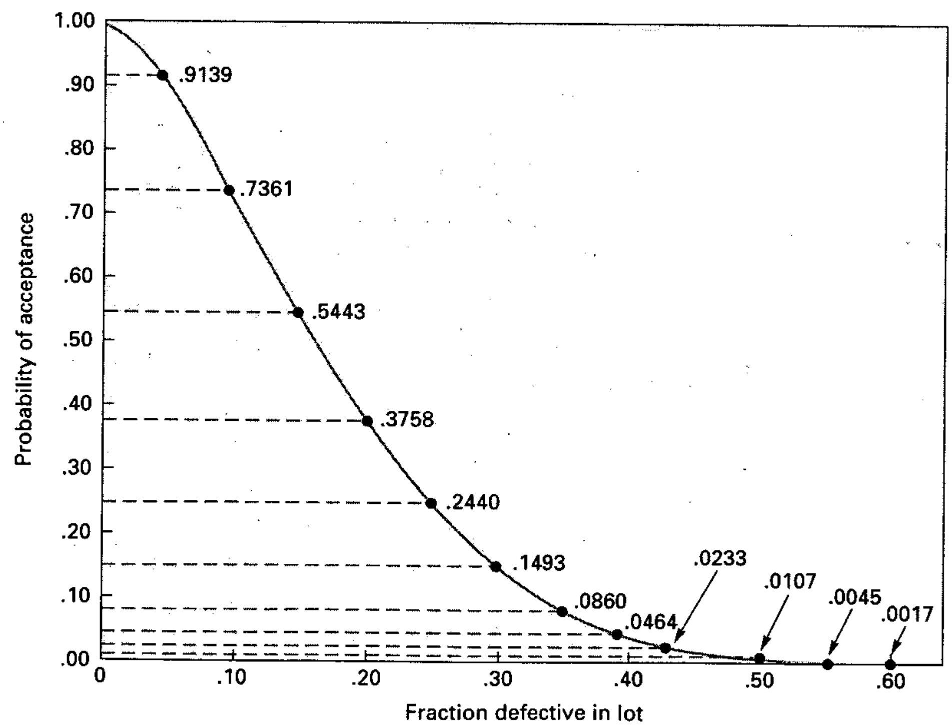
A certain amount of insight is gained by actually constructing an OC curve. Suppose you want the curve for a situation in which a sample of $n = 10$ items is drawn from lots containing $N = 2{,}000$ items, and a lot is accepted if no more than $c = 1$ defective is found. Because the sample size is small relative to the lot size, it is reasonable to use the binomial distribution to obtain the probabilities that a lot will be accepted for various lot qualities.[1] A portion of the cumulative binomial table found in Appendix B, Table D is reproduced here to facilitate the discussion.

							FRACTION DEFECTIVE, *p*						
	n	*x*	.05	.10	.15	.20	.25	.30	.35	.40	.45	.50	.55	.60
	10	0	.5987	.3487	.1969	.1074	.0563	.0282	.0135	.0060	.0025	.0010	.0003	.0001
$c = 1$ →		1	.9139	.7361	.5443	.3758	.2440	.1493	.0860	.0464	.0233	.0107	.0045	.0017
		2	.9885	.9298	.8202	.6778	.5256	.3828	.2616	.1673	.0996	.0547	.0274	.0123
		3	.9990	.9872	.9500	.8791	.7759	.6496	.5138	.3823	.2660	.1719	.1020	.0548

To use the table, select various lot qualities (values of p listed across the top of the table), beginning with .05, and find the probability that a lot with that percentage of defects would be accepted (i.e., the probability of finding zero or one defect in this case). For $p = .05$, the probability of one or no defects is .9139. For a lot with 10 percent defective (i.e., a fraction defective of .10), the probability of one or fewer defects drops to .7361, and for 15 percent defective, the probability of acceptance is .5443. In effect, you simply read the probabilities across the row for $c = 1$. By plotting these points (e.g., .05 and .9139, .10 and .7361) on a graph and connecting them, you obtain the OC curve illustrated in Figure 10S.4.

FIGURE 10S.4

OC curve for $n = 10$, $c = 1$



When $n > 20$ and $p < .05$, the Poisson distribution is useful in constructing operating characteristic curves for proportions. In effect, the Poisson distribution is used to approximate the binomial distribution. The Poisson approximation involves treating the mean of the binomial distribution (i.e., np) as the mean of the Poisson (i.e., μ):

$$\mu = np \tag{10S–1}$$

[1]Since sampling is generally performed "without replacement," if the ratio n/N is 5 percent or more, the hypergeometric distribution is more appropriate since the probability of finding a defect would vary from observation to observation. We shall consider only the more general case of the binomial distribution (i.e., $n/N < 5$ percent).

As with the binomial distribution, you select various values of lot quality, p, and then determine the probability of accepting a lot (i.e., finding two or fewer defects) by referring to the cumulative Poisson table. Values of p in increments of .01 are often used in this regard. Example S–1 illustrates this use of the Poisson table.

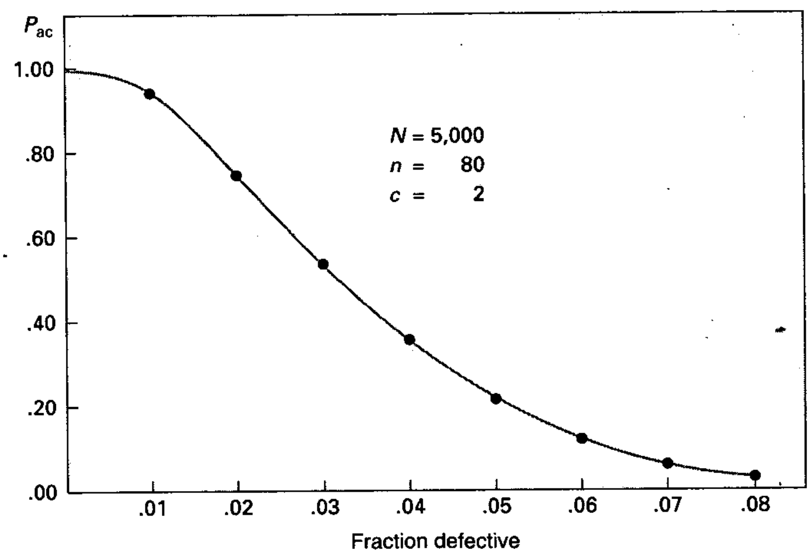
EXAMPLE S-1

Use the cumulative Poisson table to construct an OC curve for this sampling plan:

$N = 5{,}000, \quad n = 80, \quad c = 2$

SOLUTION

Selected Values of p	$\mu = np$	P_{ac} [$P(x \leq 2)$ from Appendix Table C]
.01	80(.01) = 0.8	.953
.02	80(.02) = 1.6	.783
.03	80(.03) = 2.4	.570
.04	80(.04) = 3.2	.380
.05	80(.05) = 4.0	.238
.06	80(.06) = 4.8	.143
.07	80(.07) = 5.6	.082
.08	80(.08) = 6.4	.046



Operating characteristic curves can be constructed for variables sampling plans as well as for attributes sampling plans. To go into detail is beyond the scope of this presentation. The purpose here is merely to illustrate the concept of an OC curve and to show how its construction is based on an underlying *sampling distribution.*

AVERAGE QUALITY OF INSPECTED LOTS

An interesting feature of acceptance sampling is that the level of inspection automatically adjusts to the quality of lots being inspected, assuming rejected lots are subjected to 100 percent inspection. The OC curve reveals that the greater the percentage of defects in a lot, the less likely the lot is to be accepted. Generally speaking, good lots have a high probability and bad lots have a low probability of being accepted. If the lots inspected are mostly good, few will end up going through 100 percent inspection. The poorer the quality of the lots, the greater the number of lots that will come under close scrutiny. This tends to improve overall quality of lots by weeding out defects. In this way, the level of inspection is affected by lot quality.

average outgoing quality (AOQ) Average of rejected lots (100 percent inspection) and accepted lots (a sample of items inspected).

If all lots have some given fraction defective, p, the **average outgoing quality (AOQ)** of the lots can be computed using the following formula, assuming defective items are replaced with good items:

$$\text{AOQ} = P_{ac} \times p\left(\frac{N-n}{N}\right) \quad (10S\text{–}2)$$

where

P_{ac} = Probability of accepting the lot N = Lot size
p = Fraction defective n = Sample size

In practice, the last term is often omitted since it is usually close to 1.0 and therefore has little effect on the resulting values. The formula then becomes

$$\text{AOQ} = P_{ac} \times p \quad (10S\text{–}3)$$

Use this formula instead of 10S–2 for computing AOQ values.

EXAMPLE S-2

Construct the AOQ curve for this situation:

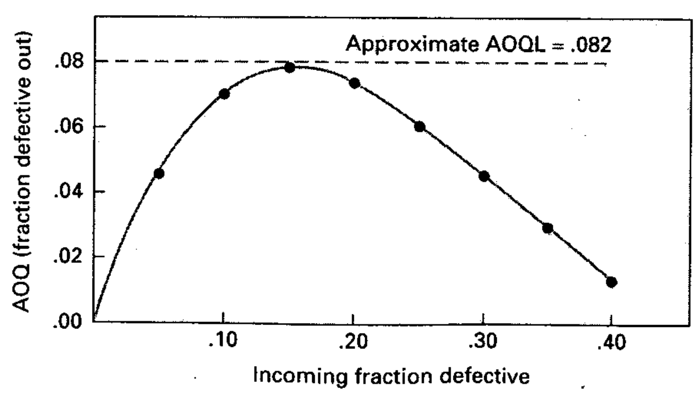
$N = 500, n = 10, c = 1$

SOLUTION

Let values of p vary from .05 to .40 in steps of .05. You can read the probabilities of acceptance, P_{ac} from Appendix B, Table D.

$\text{AOQ} = P_{ac} \times p$

p	P_{ac}	AOQ
.05	.9139	.046
.10	.7361	.074
.15	.5443	.082
.20	.3758	.075
.25	.2440	.061
.30	.1493	.045
.35	.0860	.030
.40	.0464	.019



The average outgoing quality limit (AOQL) is just above 8 percent.

By allowing the percentage, p, to vary, a curve such as the one in Example S–2 can be constructed in the same way that an OC curve is constructed. The curve illustrates the point that if lots are very good or very bad, the average outgoing quality will be high. The maximum point on the curve becomes apparent in the process of calculating values for the curve.

There are several managerial implications of the graph in Example S–2. First, a manager can determine the worst possible outgoing quality. Second, the manager can determine the amount of inspection that will be needed by obtaining an estimate of the incoming quality. Moreover, the manager can use this information to establish the relationship between inspection cost and the incoming fraction defective, thereby underscoring the benefit of implementing process improvements to reduce the incoming fraction defective rather than trying to weed out bad items through inspection.

KEY TERMS

acceptable quality level (AQL), 473
acceptance sampling, 470
average outgoing quality (AOQ), 476
consumer's risk, 473
lot tolerance percent defective (LTPD), 473
operating characteristic (OC) curve, 472
producer's risk, 473
sampling plans, 471

SOLVED PROBLEMS

Problem 1

Inspection. A process for manufacturing shock absorbers for light trucks produces 5 percent defectives. Inspection cost per shock is \$0.40, and 100 percent inspection generally catches all defects, due to the nature of the inspection and the small volume produced. Any defects installed on trucks must eventually be replaced at a cost of \$12 per shock. Is 100 percent inspection justified?

Solution

Five percent of the output is defective. The expected cost per shock for replacement is thus $.05(\$12) = 60$ cents. Since this is greater than the inspection cost per shock of 40 cents, 100 percent inspection is justified.

Problem 2

Acceptance sampling. Shipments of 300 boxes of glassware are received at a warehouse of a large department store. Random samples of five boxes are checked, and the lot is rejected if more than one box reveals breakage. Construct the OC curve for this plan.

Solution

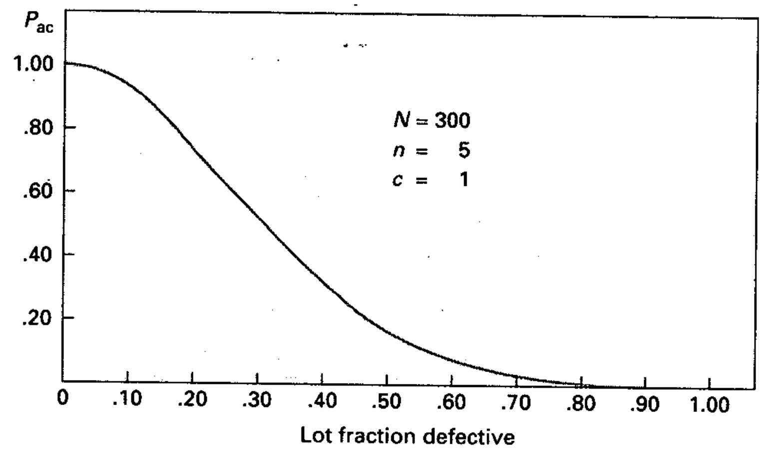
When the sample size is less than 5 percent of the lot size, the binomial distribution can be used to obtain P_{ac} for various lot percentages defective. Here, $n/N = 5/300 = .017$, so the binomial can be used. A portion of the cumulative binomial table is shown below. Note that $c = 1$.

CUMULATIVE BINOMIAL PROBABILITIES

			p = FRACTION DEFECTIVE					
	n	x	.05	.10	.15	.20	.25	.30
	5	0	.7738	.5905	.4437	.3277	.2373	.1681
c = 1	→	1	.9774	.9185	.8352	.7373	.6328	.5282
		2	.9988	.9914	.9734	.9421	.8965	.8369
		3	1.0000	.9995	.9978	.9933	.9844	.9692
		4	1.0000	1.0000	.9999	.9997	.9990	.9976
		5	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

.35	.40	.45	.50	.55	.60	.65	.70	.75	.80
.1160	.0778	.0503	.0313	.0185	.0102	.0053	.0024	.0010	.0003
.4284	.3370	.2562	.1875	.1312	.0870	.0540	.0308	.0156	.0067
.7648	.6826	.5931	.5000	.4069	.3174	.2352	.1631	.1035	.0579
.9460	.9130	.8688	.8125	.7438	.6630	.5716	.4718	.3672	.2627
.9947	.9898	.9815	.9688	.9497	.9222	.8840	.8319	.7627	.6723
1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

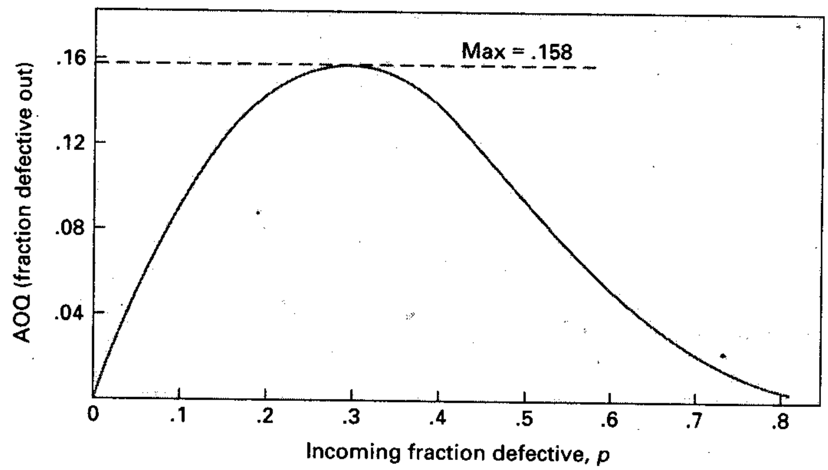
The table indicates that $P_{ac} = .9774$ when lot quality is 5 percent defective, .9185 for 10 percent defective, .8352 for 15 percent, and so on. The resulting curve is



Develop the AOQ curve for the previous problem.

$$AOQ = P_{ac} \times p$$

(Values of lot quality, p, are taken from the portion of the binomial table shown.)



p	P_{ac}	AOQ	p	P_{ac}	AOQ
.05	.9774	.049	.45	.2562	.115
.10	.9185	.092	.50	.1875	.094
.15	.8352	.125	.55	.1312	.072
.20	.7373	.147	.60	.0870	.052
.25	.6328	.158	.65	.0540	.035
.30	.5258	.158	.70	.8308	.022
.35	.4284	.150	.75	.0156	.012
.40	.3370	.135	.80	.0067	.005

DISCUSSION AND REVIEW QUESTIONS

1. What is the purpose of acceptance sampling?
2. How does acceptance sampling differ from process control?
3. What is an operating characteristic curve, and how is it useful in acceptance sampling?
4. What general factors govern the choice between single-sampling plans and multiple-sampling plans?
5. Briefly explain or define each of these terms.
   a. AOQ
   b. AOQL
   c. LTPD
   d. Producer's risk
   e. Consumer's risk

PROBLEMS

1. An assembly operation for trigger mechanisms of a semiautomatic spray gun produces a small percentage of defective mechanisms. Management must decide whether to continue the current practice of 100 percent inspection or to replace defective mechanisms after final assembly when all guns are inspected. Replacement at final assembly costs \$30 each; inspection during trigger assembly costs \$12 per hour for labor and overhead. The inspection rate is one trigger per minute.
   a. Would 100 percent inspection during trigger assembly be justified if there are (1) 4 percent defective? (2) 1 percent defective?
   b. At what point would management be indifferent between 100 percent inspection of triggers and only final inspection?
2. Random samples of $n = 20$ circuit breakers are tested for damage caused by shipment in each lot of 4,000 received. Lots with more than one defective are pulled and subjected to 100 percent inspection.
   a. Construct the OC curve for this sampling plan.
   b. Construct the AOQ curve for this plan, assuming defectives found during 100 percent inspection are replaced with good parts. What is the approximate AOQL?
3. Auditors use a technique called *discovery sampling* in which a random sample of items is inspected. If any defects are found, the entire lot of items sampled is subjected to 100 percent inspection.
   a. Draw an OC curve for the case where a sample of 15 credit accounts will be inspected out of a total of 8,000 accounts.
   b. Draw an OC curve for the case where 150 accounts out of 8,000 accounts will be examined. (Hint: Use $p = .001, .002, .003, \ldots$)
   c. Draw the AOQ curve for the preceding case, and estimate the AOQL.
4. Random samples of lots of textbooks are inspected for defective books just prior to shipment to the warehouse. Each lot contains 3,000 books.
   a. On a single graph, construct OC curves for $n = 100$ and (1) $c = 0$, (2) $c = 1$, and (3) $c = 2$. (Hint: Use $p = .001, .002, .003, \ldots$)
   b. On a single graph, construct OC curves for $c = 2$ and (1) $n = 5$, (2) $n = 20$, and (3) $n = 120$.
5. A manufacturer receives shipments of several thousand parts from a supplier every week. The manufacturer has the option of conducting a 100 percent inspection before accepting the parts. The decision is based on a random sample of 15 parts. If parts are not inspected, defectives become apparent during a later assembly operation, at which time replacement cost is \$6.25 per unit. Inspection cost for 100 percent inspection is \$1 per unit.
   a. At what fraction defective would the manufacturer be indifferent between 100 percent inspection and leaving discovery of defectives until the later assembly operation?
   b. For the sample size used, what is the maximum number of sample defectives that would cause the lot to be passed without 100 percent inspection, based on your answer to part *a*?
   c. If the shipment actually contains 5 percent defective items:
      (1) What is the correct decision?
      (2) What is the probability it would be rejected in favor of 100 percent inspection?
      (3) What is the probability that it would be accepted without 100 percent inspection?
      (4) What is the probability of a Type I error? A Type II error?
   d. Answer the questions in part *c* for a shipment that contains 20 percent defective items.
6. (Refer to Problem 5*c*.) Suppose there are two defectives in the sample.
   a. If the acceptance number is $c = 1$, what decision should be made? What type of error is possible?
   b. If the acceptance number is $c = 3$, what decision should be made? What type of error is possible?
   c. Determine the average outgoing quality for each of these percent defective if $c = 1$.
      (1) 5 percent.
      (2) 10 percent.
      (3) 15 percent.
      (4) 20 percent.

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PART FIVE

Inventory Management and Scheduling

The chapters in this part relate to the management and control of inventories, and scheduling, often key factors in the success or failure of operations management to achieve profit and/or cost objectives while satisfying customers. The basic issues are how much to order and when to order to effectively match supply and demand.

The chapters in this part cover the following topics:

CHAPTER 11

Inventory Management

LEARNING OBJECTIVES

After completing this chapter, you should be able to:

1. Define the term *inventory* and list the major reasons for holding inventories.
2. List the main requirements for effective inventory management.
3. Discuss periodic and perpetual review systems.
4. Discuss the objectives of inventory management.
5. Describe the A-B-C approach and explain how it is useful.
6. Describe the basic EOQ model and its assumptions and solve typical problems.
7. Describe the economic production quantity model and solve typical problems.
8. Describe the quantity discount model and solve typical problems.
9. Describe reorder point models and solve typical problems.
10. Describe situations in which the single-period model would be appropriate, and solve typical problems.

CHAPTER OUTLINE

Good inventory management is important for the successful operation of most businesses and their supply chains. Operations, marketing, and finance have interests in good inventory management. Poor inventory management hampers operations, diminishes customer satisfaction, and increases operating costs.

Some organizations have excellent inventory management and many have satisfactory inventory management. Too many, however, have unsatisfactory inventory management, which sometimes is a sign that management does not recognize the importance of inventories. More often than not, though, the recognition is there. What is lacking is an understanding of what needs to be done and how to do it. This chapter presents the concepts that underlie good inventory management. Topics include functions of inventories, requirements for effective inventory management, objectives of inventory control, and techniques for determining *how much* to order and *when* to order.

INTRODUCTION

An **inventory** is a stock or store of goods. Firms typically stock hundreds or even thousands of items in inventory, ranging from small things such as pencils, paper clips, screws, nuts, and bolts to large items such as machines, trucks, construction equipment, and airplanes. Naturally, many of the items a firm carries in inventory relate to the kind of business it engages in. Thus, manufacturing firms carry supplies of raw materials, purchased parts, partially finished items, and finished goods, as well as spare parts for machines, tools, and other supplies. Department stores carry clothing, furniture, carpeting, stationery, appliances, gifts, cards, and toys. Some also stock sporting goods, paints, and tools. Hospitals stock drugs, surgical

inventory A stock or store of goods.

supplies, life-monitoring equipment, sheets and pillow cases, and more. Supermarkets stock fresh and canned foods, packaged and frozen foods, household supplies, magazines, baked goods, dairy products, produce, and other items.

$$$ **NEWSCLIP**

We proceed as follows. First look for a five-by-five-by-three-foot bin of gears or parts that looks like it has been there awhile. Pick up a gear and ask, casually, "How much is this worth?" You then ask, "How many of these are in the bin?" followed by, "How long has this bin been here?" and, "What's your cost of money for this company?" I recall one case in a nameless South American country where the unit cost times the number of parts times the time it had been there times the interest rate resulted in a cost-per-day figure that would insure comfortable retirement for the plant manager on the bank of the Rio de la Plata at one of the better resorts to be found there. The plant manager suddenly realized that what he was holding was not just a chunk of high-test steel, but was *real money*. He then pointed out that *he* now understood the value of the inventory but could I suggest a way to drive the point home to upper management? I suggested that he go to the accounting department and borrow enough money to be equal to the bin's value for as long as it had been sitting there, and pile it on the top of the bin. I further suggested that he do that for every bin on the production line. We rapidly figured out that by the time we had the money piled up on the bin, you would not even be able to *see* the bin. My opinion was that if the upper managers were given a tour of the line with the money piled up, they would *never* forget it.

Source: Gene Woolsey, "On Doing Good Things and Dumb Things in Production and Inventory Control," *Interfaces* 5, no. 3 (May 1975).

THE NATURE AND IMPORTANCE OF INVENTORIES

Inventories are a vital part of business. Not only are they necessary for operations, but also they contribute to customer satisfaction. To get a sense of the significance of inventories, consider the following: Some very large firms have tremendous amounts of inventory. For example, General Motors was recently reported to have as much as $40 billion worth of materials, parts, cars, and trucks in its supply chain! Although the amounts and dollar values of inventories carried by different types of firms vary widely, a typical firm probably has about 30 percent of its current assets and perhaps as much as 90 percent of its working capital invested in inventory. One widely used measure of managerial performance relates to *return on investment* (ROI), which is profit after taxes divided by total assets. Because inventories may represent a significant portion of total assets, a reduction of inventories can result in a significant increase in ROI.

The major source of revenues for retail and wholesale businesses is the sale of merchandise (i.e., inventory). In fact, in terms of dollars, the inventory of goods held for sale is one of the largest assets of a merchandising business.

A typical manufacturing firm carries different kinds of inventories, including the following:

Raw materials and purchased parts.

Partially completed goods, called *work-in-process* (WIP).

Finished-goods inventories (manufacturing firms) or merchandise (retail stores).

Replacement parts, tools, and supplies.

Goods-in-transit to warehouses or customers (pipeline inventory).

S

Service firms do not carry these kinds of inventories, although they do carry inventories of supplies and equipment. To understand why firms have inventories at all, you need to be aware of the various functions of inventory.

Functions of Inventory

Inventories serve a number of functions. Among the most important are the following:

1. *To meet anticipated customer demand.* A customer can be a person who walks in off the street to buy a new stereo system, a mechanic who requests a tool at a tool crib, or a manufacturing operation. These inventories are referred to as *anticipation stocks* because they are held to satisfy expected (i.e., *average*) demand.

2. *To smooth production requirements.* Firms that experience seasonal patterns in demand often build up inventories during pre-season periods to meet overly high requirements during seasonal periods. These inventories are aptly named *seasonal inventories.* Companies that process fresh fruits and vegetables deal with seasonal inventories. So do stores that sell greeting cards, skis, snowmobiles, or Christmas trees.

3. *To decouple operations.* Historically, manufacturing firms have used inventories as buffers between successive operations to maintain continuity of production that would otherwise be disrupted by events such as breakdowns of equipment and accidents that cause a portion of the operation to shut down temporarily. The buffers permit other operations to continue temporarily while the problem is resolved. Similarly, firms have used buffers of raw materials to insulate production from disruptions in deliveries from suppliers, and finished goods inventory to buffer sales operations from manufacturing disruptions. More recently, companies have taken a closer look at buffer inventories, recognizing the cost and space they require, and realizing that finding and eliminating sources of disruptions can greatly decrease the need for decoupling operations.

4. *To protect against stockouts.* Delayed deliveries and unexpected increases in demand increase the risk of shortages. Delays can occur because of weather conditions, supplier stockouts, deliveries of wrong materials, quality problems, and so on. The risk of shortages can be reduced by holding *safety stocks,* which are stocks in excess of average demand to compensate for *variabilities* in demand and lead time.

5. *To take advantage of order cycles.* To minimize purchasing and inventory costs, a firm often buys in quantities that exceed immediate requirements. This necessitates storing some or all of the purchased amount for later use. Similarly, it is usually economical to produce in large rather than small quantities. Again, the excess output must be stored for later use. Thus, inventory storage enables a firm to buy and produce in *economic lot sizes* without having to try to match purchases or production with demand requirements in the short run. This results in *periodic* orders, or order *cycles.* The resulting stock is known as *cycle stock.* Order cycles are not always based on economic lot sizes. In some instances, it is practical or economical to group orders and/or to order at fixed intervals.

6. *To hedge against price increases.* Occasionally a firm will suspect that a substantial price increase is about to occur and purchase larger-than-normal amounts to beat the increase. The ability to store extra goods also allows a firm to take advantage of price discounts for larger orders.

7. *To permit operations.* The fact that production operations take a certain amount of time (i.e., they are not instantaneous) means that there will generally be some work-in-process inventory. In addition, intermediate stocking of goods—including raw materials, semifinished items, and finished goods at production sites, as well as goods stored in warehouses—leads to *pipeline* inventories throughout a production-distribution system.

8. *To take advantage of quantity discounts.* Suppliers may give discounts on large orders.

Objectives of Inventory Control

Inadequate control of inventories can result in both under- and overstocking of items. Understocking results in missed deliveries, lost sales, dissatisfied customers, and production bottlenecks; overstocking unnecessarily ties up funds that might be more productive elsewhere. Although overstocking may appear to be the lesser of the two evils, the price tag for excessive overstocking can be staggering when inventory holding costs are high—as illustrated by the little story about the bin of gears at the beginning of the chapter—and matters can easily get out of hand. It is not unheard of for managers to discover that their firm has a 10-year supply of some item. (No doubt the firm got a good buy on it!)

Inventory management has two main concerns. One is the *level of customer service,* that is, to have the right goods, in sufficient quantities, in the right place, at the right time. The other is the *costs of ordering and carrying inventories.*

The overall objective of inventory management is to achieve satisfactory levels of customer service while keeping inventory costs within reasonable bounds. Toward this end, the decision maker tries to achieve a balance in stocking. He or she must make two fundamental decisions: the *timing* and *size* of orders (i.e., when to order and how much to order). The greater part of this chapter is devoted to models that can be applied to assist in making those decisions.

inventory turnover Ratio of average cost of goods sold to average inventory investment.

Managers have a number of measures of performance they can use to judge the effectiveness of inventory management. The most obvious, of course, is customer satisfaction, which they might measure by the number and quantity of backorders and/or customer complaints. A widely used measure is **inventory turnover,** which is the ratio of annual cost of goods sold to average inventory investment. The turnover ratio indicates how many times a year the inventory is sold. Generally, the higher the ratio, the better, because that implies more efficient use of inventories. However, the desirable number of turns depends on the industry and what the profit margins are. The higher the profit margins, the lower the acceptable number of inventory turns, and vice versa. Also, a product that takes a long time to manufacture, or a long time to sell, will have a low turnover rate. This is often the case with high-end retailers (high profit margins). Conversely, supermarkets (low profit margins) have a fairly high turnover rate. Note, though, that there should be a balance between inventory investment and maintaining good customer service. Managers often use inventory turnover to evaluate inventory management performance; monitoring this metric over time can yield insights into changes in performance.

Another useful measure is days of inventory on hand, a number that indicates the expected number of days of sales that can be supplied from existing inventory. Here, a balance is desirable; a high number of days might imply excess inventory, while a low number might imply a risk of running out of stock.

REQUIREMENTS FOR EFFECTIVE INVENTORY MANAGEMENT

Management has two basic functions concerning inventory. One is to establish a system of keeping track of items in inventory, and the other is to make decisions about how much and when to order. To be effective, management must have the following:

1. A system to *keep track of the inventory* on hand and on order.
2. A reliable *forecast of demand* that includes an indication of possible *forecast error.*
3. Knowledge of *lead times* and *lead time variability.*
4. Reasonable estimates of inventory *holding costs, ordering costs,* and *shortage costs.*
5. A *classification system* for inventory items.

Let's take a closer look at each of these requirements.

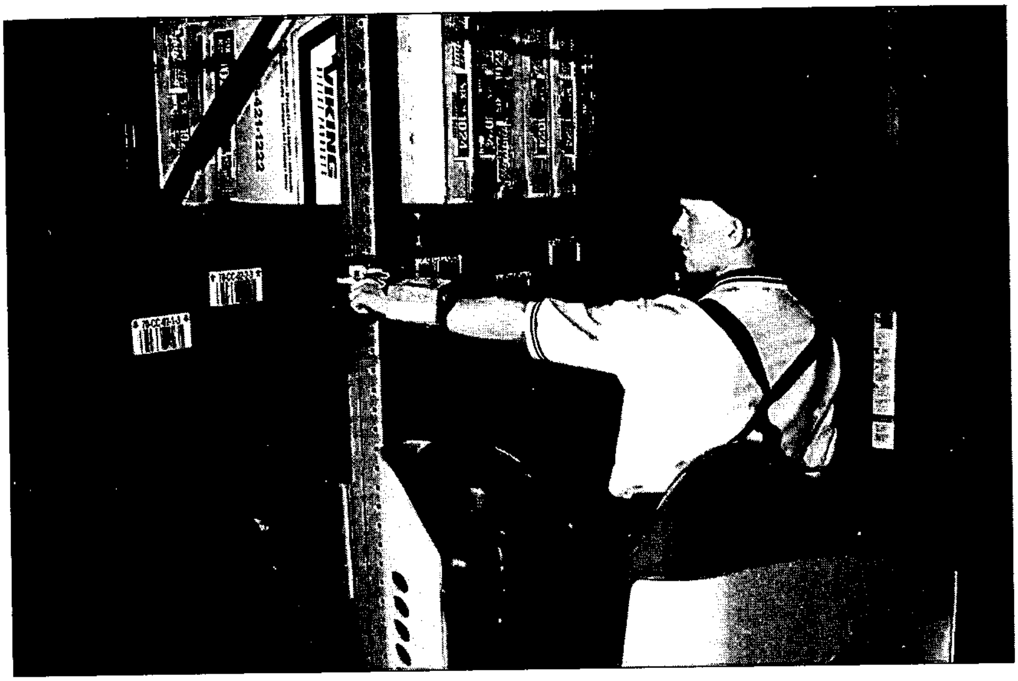
Inventory Counting Systems

periodic system Physical count of items in inventory made at periodic intervals (weekly, monthly).

Inventory counting systems can be periodic or perpetual. Under a **periodic system,** a physical count of items in inventory is made at periodic intervals (e.g., weekly, monthly) in order to decide how much to order of each item. Many small retailers use this approach: A manager periodically checks the shelves and stockroom to determine the quantity on hand. Then the manager estimates how much will be demanded prior to the next delivery period and bases the order quantity on that information. An advantage of this type of system is that orders for many items occur at the same time, which can result in economies in processing and shipping orders. There are also several disadvantages of periodic reviews. One is a lack of control between reviews. Another is the need to protect against shortages between review periods by carrying extra stock.

perpetual inventory system System that keeps track of removals from inventory continuously, thus monitoring current levels of each item.

A **perpetual inventory system** (also known as a *continual* system) keeps track of removals from inventory on a continuous basis, so the system can provide information on the current level of inventory for each item. When the amount on hand reaches a predetermined minimum,



An Office Depot employee uses a bar code scanner to quickly and accurately record inventory at their warehouse.

www.officedepot.com

a fixed quantity, Q, is ordered. An obvious advantage of this system is the control provided by the continuous monitoring of inventory withdrawals. Another advantage is the fixed-order quantity; management can determine an optimal order quantity. One disadvantage of this approach is the added cost of record keeping. Moreover, a physical count of inventories must still be performed periodically to verify records because of possible errors, pilferage, spoilage, and other factors that can reduce the effective amount of inventory. Bank transactions such as customer deposits and withdrawals are examples of continuous recording of inventory changes.

two-bin system Two containers of inventory; reorder when the first is empty.

Perpetual systems range from very simple to very sophisticated. A **two-bin system,** a very elementary system, uses two containers for inventory. Items are withdrawn from the first bin until its contents are exhausted. It is then time to reorder. Sometimes an order card is placed at the bottom of the first bin. The second bin contains enough stock to satisfy expected demand until the order is filled, plus an extra cushion of stock that will reduce the chance of a stockout if the order is late or if usage is greater than expected. The advantage of this system is that there is no need to record each withdrawal from inventory; the disadvantage is that the reorder card may not be turned in for a variety of reasons (e.g., misplaced, the person responsible forgets to turn it in).

Perpetual systems can be either *batch* or *on-line.* In batch systems, inventory records are collected periodically and entered into the system. In on-line systems, the transactions are recorded immediately. The advantage of on-line systems is that they are always up-to-date. In batch systems, a sudden surge in demand could result in reducing the amount of inventory below the reorder point between the periodic read-ins. Frequent batch collections can minimize that problem.

universal product code Bar code printed on a label that has information about the item to which it is attached.

Supermarkets, discount stores, and department stores have always been major users of periodic counting systems. Today, most have switched to computerized checkout systems using a laser scanning device that reads a **universal product code (UPC),** or *bar code,* printed on an item tag or on packaging. A typical grocery product code is illustrated here.

0 14800 23208

The zero on the left of the bar code identifies this as a grocery item, the first five numbers (14800) indicate the manufacturer (Mott's), and the last five numbers (23208) indicate the specific item (natural-style applesauce). Items in small packages, such as candy and gum, use a six-digit number.

UPC scanners represent major benefits to supermarkets. In addition to their increase in speed and accuracy, these systems give managers continuous information on inventories, reduce the need for periodic inventories and order-size determinations, and improve the level of customer service by indicating the price and quantity of each item on the customer's receipt, as illustrated below.

BRACO CAPELLINI	.79
BUB YUM DBL LIME	.30 T
2/LO FAT MILK H G	1.03
EUROP ROLLS	.91
HUNTS TOMATO	.55
NEWSPAPER	.35
KR CAS BRICK CHEES	1.59
GRAPES-GREEN	
.91 LB @ .89 PER LB	.81
TAX DUE	.02
TOTAL	6.35
CASH	20.00*
CHANGE	-13.65
8/07/04 18:01 21 16 23100 2570	

Bar coding is important for other sectors of business besides retailing. Manufacturing and service industries benefit from the simplified production and inventory control it provides. In manufacturing, bar codes attached to parts, subassemblies, and finished goods greatly facilitate counting and monitoring activities. Automatic routing, scheduling, sorting, and packaging can also be done using bar codes. In health care, use of bar codes can help to reduce drug dispensing errors.

Before long, *RFID tags* may replace bar codes in certain applications.

Chip Tags Tell Stores What's Not on the Shelf — READING

Michelle Kessler

By the end of the year, a host of consumer products will for the first time be sold with tiny computer chips known as RFID tags in them.

The chips contain bits of data, such as a product's serial number, that can be read by a scanner. The scanner sends the information to a database so stores and manufacturers can quickly track what is sold.

The radio frequency identification tags could dramatically improve inventory processes, retail analysts say, thus reducing costs and maybe consumer prices. "Everybody's going to profit from these tags," says analyst Michael Liard of research firm Venture Development.

But the technology, one of the most widely anticipated in years, also raises privacy concerns. One fear: Thieves will crack security controls and be able to scan shoppers' bags and know what they bought. Companies are testing solutions, such as turning off tags once they leave stores.

Now testing the tags:

Gillette is experimenting with chips attached to packages of razors sold in a Brockton, Mass., Wal-Mart and several British grocery stores. Chip scanners on the shelves will track supplies and, when low, alert store managers.

Procter & Gamble has tested the chips on bottles of Pantene shampoo and on Bounty towels to help track warehouse inventory and reduce lost merchandise. Next, it will tag unspecified products in an Oklahoma Wal-Mart.

Prada has tagged clothing in a New York City store since December 2001. As customers shop, scanner-wielding salespeople can quickly tell what other colors and sizes a garment comes in and if there are similar styles. Prada removes the tags before items leave the store.

Massachusetts Institute of Technology's Auto-ID research center, which designs the chip technology, is working on a

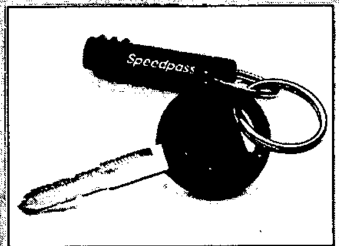
(continued)

(concluded)

widescale RFID project involving partners such as Johnson & Johnson, Coca-Cola, Pepsi, Home Depot and Target.

RFID technology is already used to track shipping containers. It's found in gas station "speed passes" that automate payment and in passes on some highway toll systems, including the New York Thruway. Until recently, however, the chips were too expensive to put on individual products.

Source: *Rochester Democrat and Chronicle,* March 10, 2003, p. 3C.



Speedpass uses RFID technology at Exxon and Mobil service stations.

www.speedpass.com

Demand Forecasts and Lead-Time Information

Inventories are used to satisfy demand requirements, so it is essential to have reliable estimates of the amount and timing of demand. Similarly, it is essential to know how long it will take for orders to be delivered. In addition, managers need to know the extent to which demand and **lead time** (the time between submitting an order and receiving it) might vary; the greater the potential variability, the greater the need for additional stock to reduce the risk of a shortage between deliveries. Thus, there is a crucial link between forecasting and inventory management.

lead time Time interval between ordering and receiving the order.

Point-of sale (POS) systems electronically record actual sales. Knowledge of actual sales can greatly enhance forecasting and inventory management: By relaying information about actual demand in real time, these systems enable management to make any necessary changes to restocking decisions. These systems are being increasingly emphasized as an important input to effective supply chain management by making this information available to suppliers.

point-of-sale (POS) systems Record items at time of sale.

Inventory Costs

Three basic costs are associated with inventories: holding, transaction (ordering), and shortage costs.

Holding or **carrying costs** relate to physically having items in storage. Costs include interest, insurance, taxes (in some states), depreciation, obsolescence, deterioration, spoilage, pilferage, breakage, and warehousing costs (heat, light, rent, security). They also include opportunity costs associated with having funds that could be used elsewhere tied up in inventory. Note that it is the *variable* portion of these costs that is pertinent.

holding (carrying) cost Cost to carry an item in inventory for a length of time, usually a year.

The significance of the various components of holding cost depends on the type of item involved, although taxes, interest, and insurance are generally based on the dollar value of an inventory. Items that are easily concealed (e.g., pocket cameras, transistor radios, calculators) or fairly expensive (cars, TVs) are prone to theft. Fresh seafood, meats and poultry, produce, and baked goods are subject to rapid deterioration and spoilage. Dairy products, salad dressings, medicines, batteries, and film also have limited shelf lives.

Holding costs are stated in either of two ways: as a percentage of unit price or as a dollar amount per unit. Typical annual holding costs range from 20 percent to 40 percent of the value of an item. In other words, to hold a $100 item in inventory for one year could cost from $20 to $40.

Ordering costs are the costs of ordering and receiving inventory. They are the costs that vary with the actual placement of an order. Besides shipping costs, they include determining how much is needed, preparing invoices, shipping costs, inspecting goods upon arrival for quality and quantity, and moving the goods to temporary storage. Ordering costs are generally expressed as a fixed dollar amount per order, regardless of order size.

ordering costs Costs of ordering and receiving inventory.

When a firm produces its own inventory instead of ordering it from a supplier, the costs of machine setup (e.g., preparing equipment for the job by adjusting the machine, changing cutting tools) are analogous to ordering costs; that is, they are expressed as a fixed charge per production run, regardless of the size of the run.

Shortage costs result when demand exceeds the supply of inventory on hand. These costs can include the opportunity cost of not making a sale, loss of customer goodwill, late charges,

shortage costs Costs resulting when demand exceeds the supply of inventory; often unrealized profit per unit.

and similar costs. Furthermore, if the shortage occurs in an item carried for internal use (e.g., to supply an assembly line), the cost of lost production or downtime is considered a shortage cost. Such costs can easily run into hundreds of dollars a minute or more. Shortage costs are sometimes difficult to measure, and they may be subjectively estimated.

Ford Triples Its Billion-Dollar Cost-Cutting Goal NEWSCLIP

www.ford.com

The Ford Motor Company exceeded its original goal of cutting out $1 billion in costs in 1997. One major chunk of savings was the result of worker suggestions; in one case teams from two assembly plants visited each others' plants and offered suggestions on ways to improve production. Another major chunk came from the use of standard parts—using the same parts in different models. Not only did this reduce design and assembly costs, it reduced the number of different parts carried in inventory, and simplified record keeping. At the same time, it increased production flexibility. Beyond that, standard parts help lessen the chance of experiencing out-of-stock incidents, which can result in costly shutdowns at assembly plants; and standard parts mean dealers don't have to carry as many different replacement parts.

Source: Based in part on "Ford Triples Its Billion-Dollar Cost-Cutting Goal," Micheline Maynard, *USA TODAY*, December 15, 1997, p. 1B.

Classification System

An important aspect of inventory management is that items held in inventory are not of equal importance in terms of dollars invested, profit potential, sales or usage volume, or stockout penalties. For instance, a producer of electrical equipment might have electric generators, coils of wire, and miscellaneous nuts and bolts among the items carried in inventory. It would be unrealistic to devote equal attention to each of these items. Instead, a more reasonable approach would be to allocate control efforts according to the *relative importance* of various items in inventory.

A-B-C approach Classifying inventory according to some measure of importance, and allocating control efforts accordingly.

The **A-B-C approach** classifies inventory items according to some measure of importance, usually annual dollar value (i.e., dollar value per unit multiplied by annual usage rate), and then allocates control efforts accordingly. Typically, three classes of items are used: A (very important), B (moderately important), and C (least important). However, the actual number of categories may vary from organization to organization, depending on the extent to which a firm wants to differentiate control efforts. With three classes of items, A items generally

A gas lineman for a public works company is processing data on a worksite in Ventura, California. Entering and processing data on site allows for more accurate, up-to-date records of costs as well as inventory for repairs and replacement of gas lines.

account for about 10 to 20 percent of the *number* of items in inventory but about 60 to 70 percent of the *annual dollar value.* At the other end of the scale, C items might account for about 50 to 60 percent of the number of items but only about 10 to 15 percent of the dollar value of an inventory. These percentages vary from firm to firm, but in most instances a relatively small number of items will account for a large share of the value or cost associated with an inventory, and these items should receive a relatively greater share of control efforts. For instance, A items should receive close attention through frequent reviews of amounts on hand and control over withdrawals, where possible, to make sure that customer service levels are attained. The C items should receive only loose control (two-bin system, bulk orders), and the B items should have controls that lie between the two extremes.

Note that C items are not necessarily *un*important; incurring a stockout of C items such as the nuts and bolts used to assemble manufactured goods can result in a costly shutdown of an assembly line. However, due to the low annual dollar value of C items, there may not be much additional cost incurred by ordering larger quantities of some items, or ordering them a bit earlier.

EXAMPLE 1

The annual dollar value of 12 items has been calculated based on annual demand and unit cost. The annual dollar values were then arrayed from highest to lowest to simplify classification of items. (Notice that the item numbers are not in what would have been their original sequence due to arraying by annual dollar values.)

Item Number	Annual Demand	×	Unit Cost	=	Annual Dollar Value	Classification
8	1,000		$4,000		$ 4,000,000	A
5	3,900		700		2,730,000	A
3	1,900		500		950,000	B
6	1,000		915		915,000	B
1	2,500		330		825,000	B
4	1,500		100		150,000	C
12	400		300		120,000	C
11	500		200		100,000	C
9	8,000		10		80,000	C
2	1,000		70		70,000	C
7	200		210		42,000	C
10	9,000		2		18,000	C
					10,000,000	

The first two items have a relatively high annual dollar value, so it seems reasonable to classify them as A items. The next three items appear to have moderate annual dollar values and should be classified as B items. The remainder are C items, based on their relatively low annual dollar value.

Although annual dollar value may be the primary factor in classifying inventory items, a manager may take other factors into account in making exceptions for certain items (e.g., changing the classification of a B item to an A item). Factors may include the risk of obsolescence, the risk of a stockout, the distance of a supplier, and so on.

Figure 11.1 illustrates the A-B-C concept.

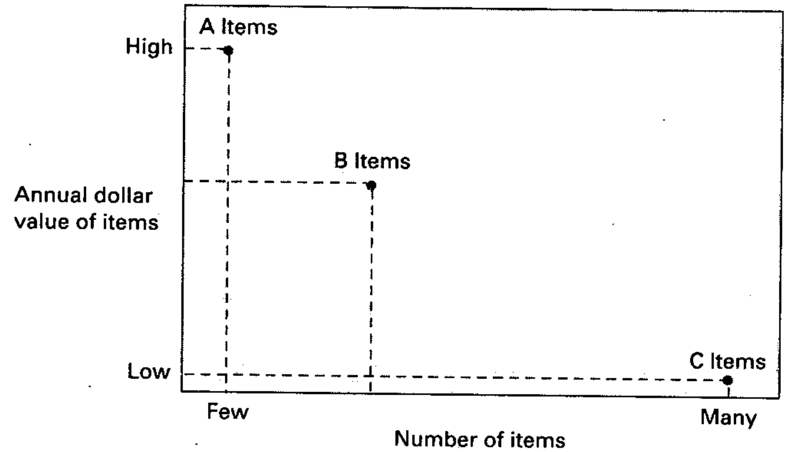
Managers use the A-B-C concept in many different settings to improve operations. One key use occurs in customer service, where a manager can focus attention on the most important aspects of customer service by categorizing different aspects as very important, important, or of only minor importance. The point is to not overemphasize minor aspects of customer service at the expense of major aspects.

Another application of the A-B-C concept is as a guide to **cycle counting,** which is a physical count of items in inventory. The purpose of cycle counting is to reduce discrepancies between the amounts indicated by inventory records and the actual quantities of inventory on

cycle counting A physical count of items in inventory.

FIGURE 11.1

A typical A-B-C breakdown in relative annual dollar value of items and number of items by category



hand. Accuracy is important because inaccurate records can lead to disruptions in operations, poor customer service, and unnecessarily high inventory carrying costs. The counts are conducted more frequently than once a year, which reduces the costs of inaccuracies compared to only doing an annual count, by allowing for investigation and correction of the causes of inaccuracies.

The key questions concerning cycle counting for management are

1. How much accuracy is needed?
2. When should cycle counting be performed?
3. Who should do it?

APICS recommends the following guidelines for inventory record accuracy: ±0.2 percent for A items, ±1 percent for B items, and ±5 percent for C items. A items are counted frequently, B items are counted less frequently, and C items are counted the least frequently.

Some companies use certain events to trigger cycle counting, whereas others do it on a periodic (scheduled) basis. Events that can trigger a physical count of inventory include an out-of-stock report written on an item indicated by inventory records to be in stock, an inventory report that indicates a low or zero balance of an item, and a specified level of activity (e.g., every 2,000 units sold).

Some companies use regular stockroom personnel to do cycle counting during periods of slow activity while others contract with outside firms to do it on a periodic basis. Use of an outside firm provides an independent check on inventory and may reduce the risk of problems created by dishonest employees. Still other firms maintain full-time personnel to do cycle counting.

HOW MUCH TO ORDER: ECONOMIC ORDER QUANTITY MODELS

economic order quantity (EOQ) The order size that minimizes total annual cost.

The question of how much to order is frequently determined by using an **economic order quantity (EOQ)** model. EOQ models identify the optimal order quantity by minimizing the sum of certain annual costs that vary with order size. Three order size models are described here:

1. The basic economic order quantity model.
2. The economic production quantity model.
3. The quantity discount model.

Basic Economic Order Quantity (EOQ) Model

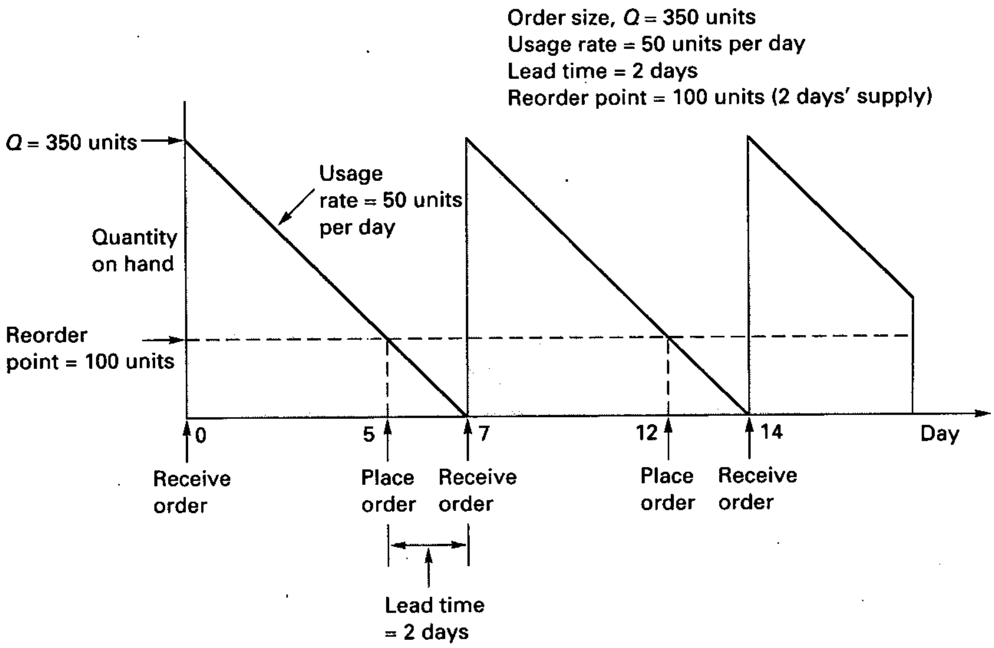
IOM

The basic EOQ model is the simplest of the three models. It is used to identify a *fixed* order size that will minimize the sum of the annual costs of holding inventory and ordering inventory. The unit purchase price of items in inventory is not generally included in the total cost because the

TABLE 11.1
Assumptions of the basic EOQ model

1. Only one product is involved.
2. Annual demand requirements are known.
3. Demand is spread evenly throughout the year so that the demand rate is reasonably constant.
4. Lead time does not vary.
5. Each order is received in a single delivery.
6. There are no quantity discounts.

FIGURE 11.2
The inventory cycle: profile of inventory level over time



unit cost is unaffected by the order size unless quantity discounts are a factor. If holding costs are specified as a percentage of unit cost, then unit cost is indirectly included in the total cost as a part of holding costs.

The basic model involves a number of assumptions. They are listed in Table 11.1.

Inventory ordering and usage occur in cycles. Figure 11.2 illustrates several inventory cycles. A cycle begins with receipt of an order of Q units, which are withdrawn at a constant rate over time. When the quantity on hand is just sufficient to satisfy demand during lead time, an order for Q units is submitted to the supplier. Because it is assumed that both the usage rate and the lead time do not vary, the order will be received at the precise instant that the inventory on hand falls to zero. Thus, orders are timed to avoid both excess stock and stockouts (i.e., running out of stock).

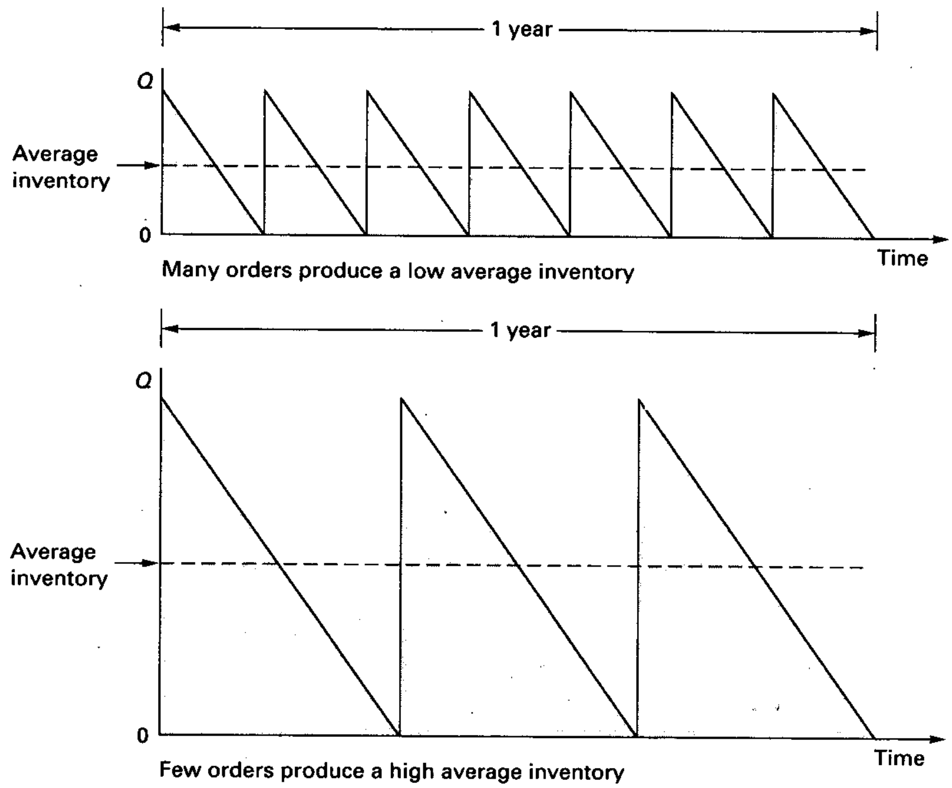
The optimal order quantity reflects a balance between carrying costs and ordering costs: As order size varies, one type of cost will increase while the other decreases. For example, if the order size is relatively small, the average inventory will be low, resulting in low carrying costs. However, a small order size will necessitate frequent orders, which will drive up annual ordering costs. Conversely, ordering large quantities at infrequent intervals can hold down annual ordering costs, but that would result in higher average inventory levels and therefore increased carrying costs. Figure 11.3 illustrates these two extremes.

Thus, the ideal solution is an order size that causes neither a few very large orders nor many small orders, but one that lies somewhere between. The exact amount to order will depend on the relative magnitudes of carrying and ordering costs.

Annual carrying cost is computed by multiplying the average amount of inventory on hand by the cost to carry one unit for one year, even though any given unit would not necessarily be held for a year. The average inventory is simply half of the order quantity: The amount on hand

FIGURE 11.3

Average inventory level and number of orders per year are inversely related: as one increases, the other decreases



decreases steadily from Q units to 0, for an average of $(Q + 0)/2$, or $Q/2$. Using the symbol H to represent the average annual carrying cost per unit, the *total annual carrying cost* is

$$\text{Annual carrying cost} = \frac{Q}{2}H$$

where

Q = Order quantity in units
H = Holding (carrying) cost per unit

Carrying cost is thus a linear function of Q: Carrying costs increase or decrease in direct proportion to changes in the order quantity Q, as Figure 11.4A illustrates.

On the other hand, annual ordering cost will decrease as order size increases because, for a given annual demand, the larger the order size, the fewer the number of orders needed. For instance, if annual demand is 12,000 units and the order size is 1,000 units per order, there must be 12 orders over the year. But if Q = 2,000 units, only six orders will be needed; if Q = 3,000 units, only four orders will be needed. In general, the number of orders per year will be D/Q, where D = Annual demand and Q = Order size. Unlike carrying costs, ordering costs are relatively insensitive to order size; regardless of the amount of an order, certain activities must be done, such as determining how much is needed, periodically evaluating sources of supply, and preparing the invoice. Even inspection of the shipment to verify quality and quantity characteristics is not strongly influenced by order size since large shipments are sampled rather than completely inspected. Hence, ordering cost is treated as a constant. *Annual ordering cost* is a function of the number of orders per year and the ordering cost per order:

$$\text{Annual ordering cost} = \frac{D}{Q}S$$

where

D = Demand, usually in units per year
S = Ordering cost

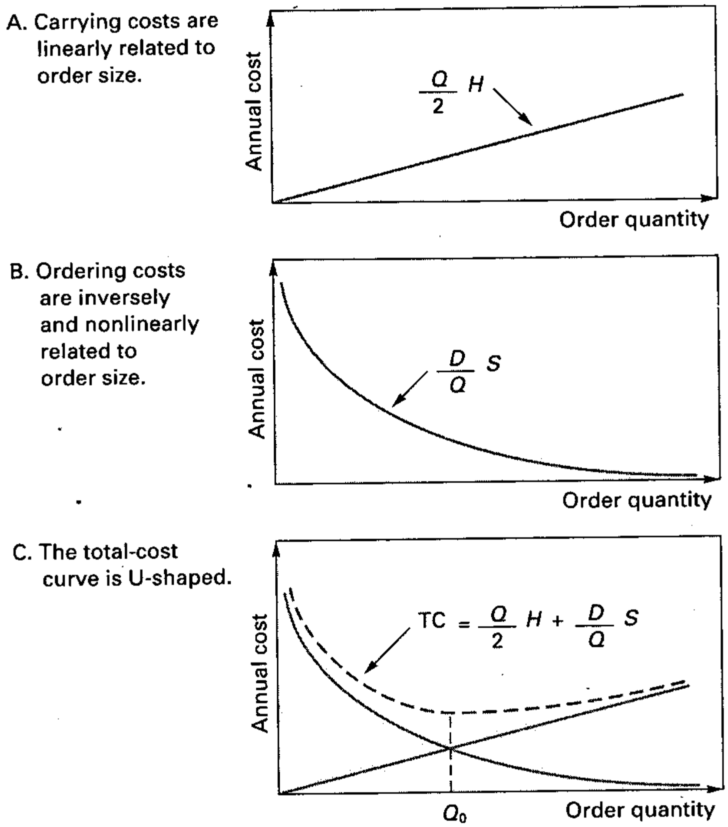


FIGURE 11.4

Carrying cost, ordering cost, and total cost curve

Because the number of orders per year, D/Q, decreases as Q increases, annual ordering cost is inversely related to order size, as Figure 11.4B illustrates.

The total annual cost associated with carrying and ordering inventory when Q units are ordered each time is

$$\text{TC} = \text{Annual carrying cost} + \text{Annual ordering cost} = \frac{Q}{2}H + \frac{D}{Q}S \qquad (11\text{–}1)$$

(Note that D and H must be in the same units, e.g., months, years.) Figure 11.4C reveals that the total-cost curve is U-shaped (i.e., convex, with one minimum) and that *it reaches its minimum at the quantity where carrying and ordering costs are equal.* An expression for the optimal order quantity, Q_0, can be obtained using calculus.[1] The result is the formula

$$Q_0 = \sqrt{\frac{2DS}{H}} \qquad (11\text{–}2)$$

Thus, given annual demand, the ordering cost per order, and the annual carrying cost per unit, one can compute the optimal (economic) order quantity. The minimum total cost is then found by substituting Q_0 for Q in Formula 11–1.

[1]We can find the minimum point of the total-cost curve by differentiating TC with respect to Q, setting the result equal to zero, and solving for Q. Thus,

1. $\frac{d\text{TC}}{dQ} = \frac{dQ}{2}H + d(D/Q)S = H/2 - DS/Q^2$

2. $0 = H/2 - DS/Q^2$, so $Q^2 = \frac{2DS}{H}$ and $Q = \sqrt{\frac{2DS}{H}}$

Note that the second derivative is positive, which indicates a minimum has been obtained.

The length of an order cycle (i.e., the time between orders) is

$$\text{Length of order cycle} = \frac{Q_0}{D} \tag{11–3}$$

EXAMPLE 2

A local distributor for a national tire company expects to sell approximately 9,600 steel-belted radial tires of a certain size and tread design next year. Annual carrying cost is $16 per tire, and ordering cost is $75. The distributor operates 288 days a year.

a. What is the EOQ?

b. How many times per year does the store reorder?

c. What is the length of an order cycle?

d. What is the total annual cost if the EOQ quantity is ordered?

SOLUTION

D = 9,600 tires per year
H = $16 per unit per year
S = $75

a. $Q_0 = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(9{,}600)75}{16}} = 300$ tires

b. Number of orders per year: $D/Q_0 = \frac{9{,}600 \text{ tires}}{300 \text{ tires}} = 32.$

c. Length of order cycle: $Q_0/D = \frac{300 \text{ tires}}{9{,}600 \text{ tires/yr}} = \frac{1}{32}$ of a year, which is $\frac{1}{32} \times 288$, or nine workdays.

d. TC = Carrying cost + Ordering cost
$= (Q_0/2)H + (D/Q_0)S$
$= (300/2)16 + (9{,}600/300)75$
$= \$2{,}400 + \$2{,}400$
$= \$4{,}800.$

Note that the ordering and carrying costs are equal at the EOQ, as illustrated in Figure 11.4C.

Carrying cost is sometimes stated as a percentage of the purchase price of an item rather than as a dollar amount per unit. However, as long as the percentage is converted into a dollar amount, the EOQ formula is still appropriate.

EXAMPLE 3

Piddling Manufacturing assembles security monitors. It purchases 3,600 black-and-white cathode ray tubes a year at $65 each. Ordering costs are $31, and annual carrying costs are 20 percent of the purchase price. Compute the optimal quantity and the total annual cost of ordering and carrying the inventory.

SOLUTION

D = 3,600 cathode ray tubes per year
S = $31
$H = .20(\$65) = \$13$

$Q_0 = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(3{,}600)(31)}{13}} \approx 131$ cathode ray tubes

TC = Carrying costs + Ordering costs
$= \quad (Q_0/2)H \quad + \quad (D/Q_0)S$

$$= (131/2)13 + (3{,}600/131)31$$
$$= \$852 + \$852 = \$1{,}704$$

Comment. Holding and ordering costs, and annual demand, are typically estimated values rather than values that can be precisely determined, say, from accounting records. Holding costs are sometimes *designated* by management rather than computed. Consequently, the EOQ should be regarded as an *approximate* quantity rather than an exact quantity. Thus, rounding the calculated value is perfectly acceptable; stating a value to several decimal places would tend to give an unrealistic impression of the precision involved. An obvious question is: How good is this "approximate" EOQ in terms of minimizing cost? The answer is that the EOQ is fairly robust; the total cost curve is relatively flat near the EOQ, especially to the right of the EOQ. In other words, even if the resulting EOQ differs from the actual EOQ, total costs will not increase much at all. This is particularly true for quantities larger than the real EOQ, because the total cost curve rises very slowly to the right of the EOQ. (See Figure 11.5.)

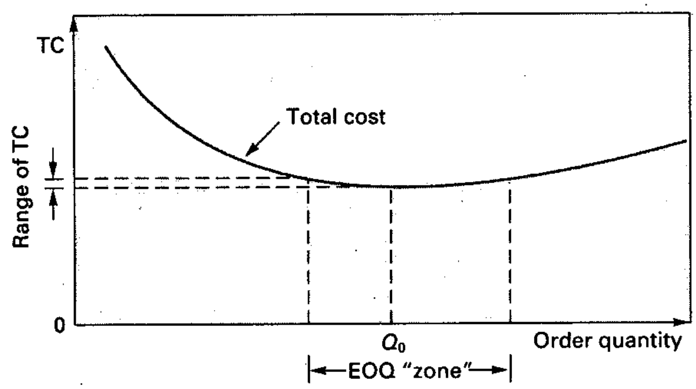
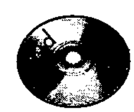


FIGURE 11.5

The total-cost curve is relatively flat near the EOQ

Economic Production Quantity (EPQ)



Tutorial

The batch mode of production is widely used in production. Even in assembly operations, portions of the work are done in batches. The reason for this is that in certain instances, the capacity to produce a part exceeds the part's usage or demand rate. As long as production continues, inventory will continue to grow. In such instances, it makes sense to periodically produce such items in batches, or *lots,* instead of producing continually

The assumptions of the EPQ model are similar to those of the EOQ model, except that instead of orders received in a single delivery, units are received incrementally during production. The assumptions are

1. Only one item is involved.
2. Annual demand is known.
3. The usage rate is constant.
4. Usage occurs continually, but production occurs periodically.
5. The production rate is constant.
6. Lead time does not vary.
7. There are no quantity discounts.

Figure 11.6 illustrates how inventory is affected by periodically producing a batch of a particular item.

During the production phase of the cycle, inventory builds up at a rate equal to the difference between production and usage rates. For example, if the daily production rate is 20 units and the daily usage rate is 5 units, inventory will build up at the rate of 20 − 5 = 15 units per day. As long as production occurs, the inventory level will continue to build; when production ceases, the inventory level will begin to decrease. Hence, the inventory level will be maximum

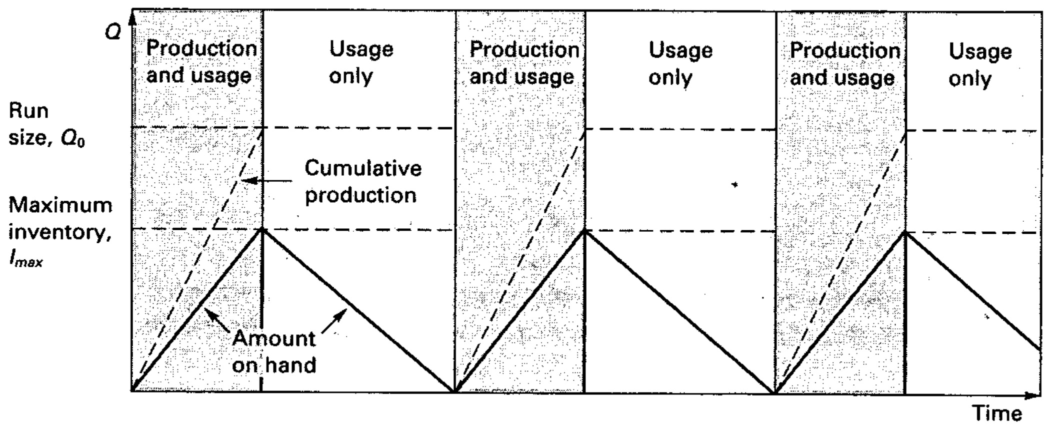


FIGURE 11.6
EOQ with incremental inventory replenishment

at the point where production ceases. When the amount of inventory on hand is exhausted, production is resumed, and the cycle repeats itself.

Because the company makes the product itself, there are no ordering costs as such. Nonetheless, with every production run (batch) there are setup costs—the costs required to prepare the equipment for the job, such as cleaning, adjusting, and changing tools and fixtures. Setup costs are analogous to ordering costs because they are independent of the lot (run) size. They are treated in the formula in exactly the same way. The larger the run size, the fewer the number of runs needed and, hence, the lower the annual setup cost. The number of runs or batches per year is D/Q, and the annual setup cost is equal to the number of runs per year times the setup cost, S, per run: $(D/Q)S$.

The total cost is

$$TC_{min} = \text{Carrying cost} + \text{Setup cost} = \left(\frac{I_{max}}{2}\right)H + (D/Q_0)S \quad (11\text{–}4)$$

where

I_{max} = Maximum inventory

The economic run quantity is

$$Q_0 = \sqrt{\frac{2DS}{H}}\sqrt{\frac{p}{p-u}} \quad (11\text{–}5)$$

where

p = Production or delivery rate
u = Usage rate

The cycle time (the time between orders or between the beginnings of runs) for the economic run size model is a function of the run size and usage (demand) rate:

$$\text{Cycle time} = \frac{Q_0}{u} \quad (11\text{–}6)$$

Similarly, the run time (the production phase of the cycle) is a function of the run (lot) size and the production rate:

$$\text{Run time} = \frac{Q_0}{p} \quad (11\text{–}7)$$

The maximum and average inventory levels are

$$I_{max} = \frac{Q_0}{p}(p-u) \quad \text{and} \quad I_{average} = \frac{I_{max}}{2} \quad (11\text{–}8)$$

EXAMPLE 4

A toy manufacturer uses 48,000 rubber wheels per year for its popular dump truck series. The firm makes its own wheels, which it can produce at a rate of 800 per day. The toy trucks are assembled uniformly over the entire year. Carrying cost is $1 per wheel a year. Setup cost for a production run of wheels is $45. The firm operates 240 days per year. Determine the

a. Optimal run size.
b. Minimum total annual cost for carrying and setup.
c. Cycle time for the optimal run size.
d. Run time.

SOLUTION

D = 48,000 wheels per year
S = $45
H = $1 per wheel per year
p = 800 wheels per day
u = 48,000 wheels per 240 days, or 200 wheels per day

a. $$Q_0 = \sqrt{\frac{2DS}{H}}\sqrt{\frac{p}{p-u}} = \sqrt{\frac{2(48{,}000)45}{1}}\sqrt{\frac{800}{800-200}} = 2{,}400 \text{ wheels}$$

b. $$\text{TC}_{\min} = \text{Carrying cost} + \text{Setup cost} = \left(\frac{I_{max}}{2}\right)H + (D/Q_0)S$$

Thus, you must first compute I_{max}:

$$I_{max} = \frac{Q_0}{p}(p-u) = \frac{2{,}400}{800}(800-200) = 1{,}800 \text{ wheels}$$

$$\text{TC} = \frac{1{,}800}{2} \times \$1 + \frac{48{,}000}{2{,}400} \times \$45 = \$900 + \$900 = \$1{,}800$$

Note again the equality of cost (in this example, setup and carrying costs) at the EOQ.

c. $$\text{Cycle time} = \frac{Q_0}{u} = \frac{2{,}400 \text{ wheels}}{200 \text{ wheels per day}} = 12 \text{ days}$$

Thus, a run of wheels will be made every 12 days.

d. $$\text{Run time} = \frac{Q_0}{p} = \frac{2{,}400 \text{ wheels}}{800 \text{ wheels per day}} = 3 \text{ days}$$

Thus, each run will require three days to complete.

Quantity Discounts

Quantity discounts are price reductions for large orders offered to customers to induce them to buy in large quantities. For example, a Chicago surgical supply company publishes the price list shown in Table 11.2 for boxes of gauze strips. Note that the price per box decreases as order quantity increases.

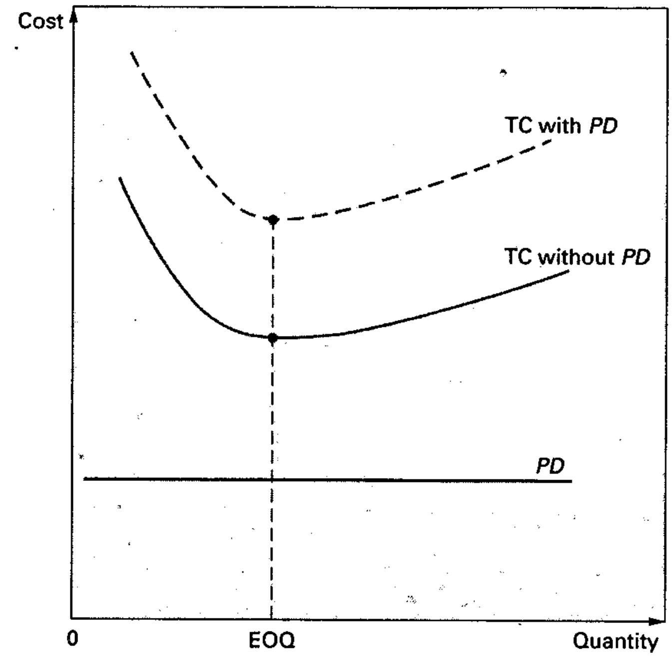
quantity discounts Price reductions for large orders.

Order Quantity	Price per Box
1 to 44	$2.00
45 to 69	1.70
70 or more	1.40

TABLE 11.2
Price list for extra-wide gauze strips

FIGURE 11.7

Adding *PD* doesn't change the EOQ



If quantity discounts are offered, the buyer must weigh the potential benefits of reduced purchase price and fewer orders that will result from buying in large quantities against the increase in carrying costs caused by higher average inventories. The buyer's goal with quantity discounts is to select the order quantity that will minimize total cost, where total cost is the sum of carrying cost, ordering cost, *and* purchasing (i.e., product) cost:

$$\text{TC} = \text{Carrying cost} + \text{Ordering cost} + \text{Purchasing cost} \qquad (11\text{–}9)$$

$$= \left(\frac{Q}{2}\right)H + \left(\frac{D}{Q}\right)S + PD$$

where

P = Unit price

Recall that in the basic EOQ model, determination of order size does not involve the purchasing cost. The rationale for not including unit price is that under the assumption of no quantity discounts, price per unit is the same for all order sizes. Inclusion of unit price in the total-cost computation in that case would merely increase the total cost by the amount P times D. A graph of total annual purchase cost versus quantity would be a horizontal line. Hence, including purchasing costs would merely raise the total-cost curve by the same amount (PD) at every point. That would not change the EOQ. (See Figure 11.7.)

When quantity discounts are offered, there is a separate U-shaped total-cost curve for each unit price. Again, including unit prices merely raises each curve by a constant amount. However, because the unit prices are all different, each curve is raised by a different amount: Smaller unit prices will raise a total-cost curve less than larger unit prices. Note that no one curve applies to the entire range of quantities; each curve applies to only a *portion* of the range. (See Figure 11.8.) Hence, the applicable or *feasible* total cost is initially on the curve with the highest unit price and then drops down, curve by curve, at the *price breaks,* which are the minimum quantities needed to obtain the discounts. Thus, in Table 11.2, the price breaks for gauze strips are at 45 and 70 boxes. The result is a total-cost curve with *steps* at the price breaks.

Even though each curve has a minimum, those points are not necessarily feasible. For example, the minimum point for the $1.40 curve in Figure 11.8 appears to be about 65 units. However, the price list shown in Table 11.2 indicates that an order size of 65 boxes will involve a unit price of $1.70. The actual total-cost curve is denoted by the solid lines; only those

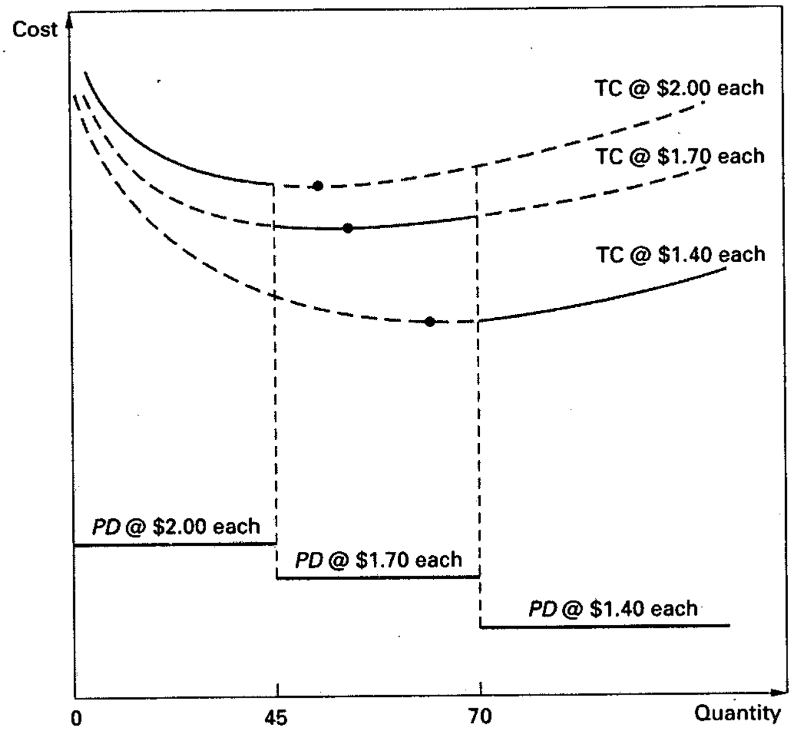


FIGURE 11.8

The total-cost curve with quantity discounts is composed of a portion of the total-cost curve for each price

price–quantity combinations are feasible. The objective of the quantity discount model is to identify the order quantity that will represent the lowest total cost for the entire set of curves.

There are two general cases of the model. In one, carrying costs are constant (e.g., $2 per unit); in the other, carrying costs are stated as a percentage of purchase price (e.g., 20 percent of unit price). When carrying costs are constant, there will be a single minimum point: All curves will have their minimum point at the same quantity. Consequently, the total-cost curves line up vertically, differing only in that the lower unit prices are reflected by lower total-cost curves as shown in Figure 11.9A. (For purposes of illustration, the horizontal purchasing cost lines have been omitted.)

When carrying costs are specified as a percentage of unit price, each curve will have a different minimum point. Because carrying costs are a percentage of price, lower prices will mean lower carrying costs and larger minimum points. Thus, as price decreases, each curve's minimum point will be to the right of the next higher curve's minimum point. (See Figure 11.9B.)

The procedure for determining the overall EOQ differs slightly, depending on which of these two cases is relevant. For carrying costs that are constant, the procedure is as follows:

1. Compute the common minimum point.
2. Only one of the unit prices will have the minimum point in its feasible range since the ranges do not overlap. Identify that range.
   a. If the feasible minimum point is on the lowest price range, that is the optimal order quantity.
   b. If the feasible minimum point is in any other range, compute the total cost for the minimum point and for the price breaks of all *lower* unit costs. Compare the total costs; the quantity (minimum point or price break) that yields the lowest total cost is the optimal order quantity.

EXAMPLE 5

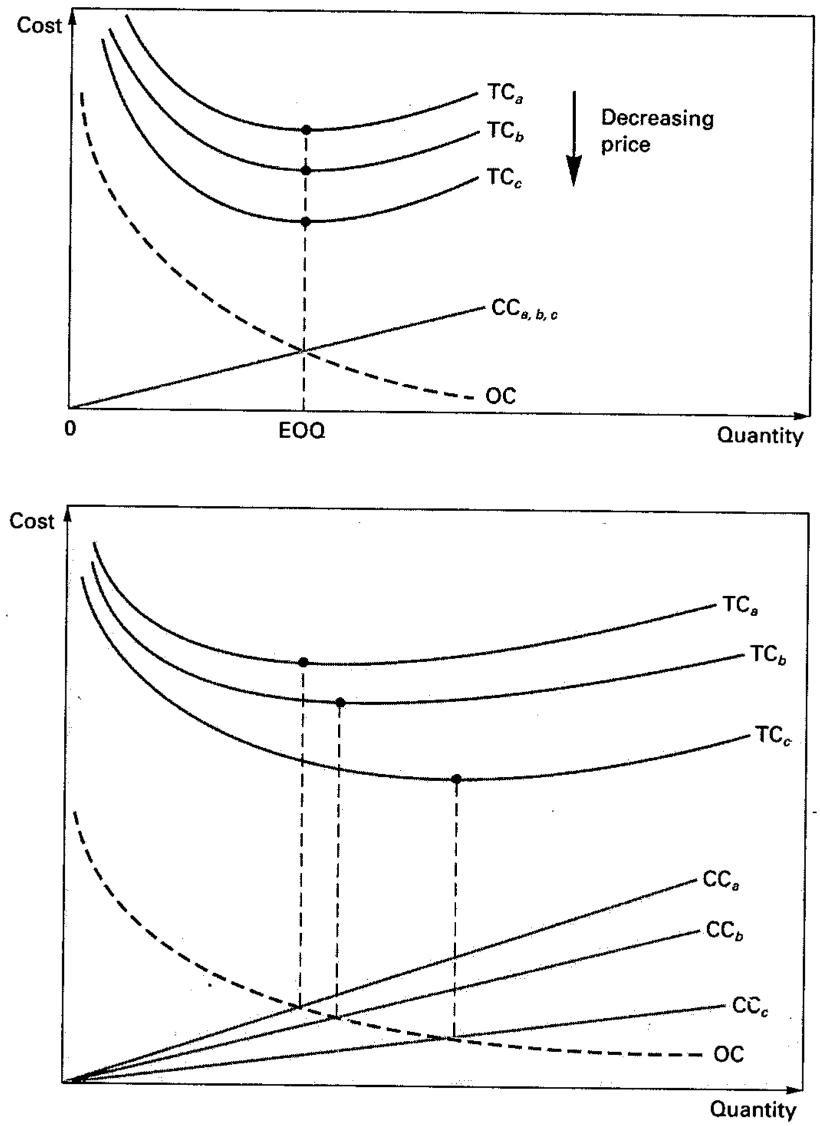
The maintenance department of a large hospital uses about 816 cases of liquid cleanser annually. Ordering costs are $12, carrying costs are $4 per case a year, and the new price schedule indicates that orders of less than 50 cases will cost $20 per case, 50 to 79 cases will cost $18 per case, 80 to 99 cases will cost $17 per case, and larger orders will cost $16 per case. Determine the optimal order quantity and the total cost.

FIGURE 11.9

Comparison of TC curves for constant carrying costs and carrying costs that are a percentage of unit costs

A. When carrying costs are constant, all curves have their minimum points at the same quantity.

B. When carrying costs are stated as a percentage of unit price, the minimum points do not line up.



SOLUTION

See Figure 11.10:

D = 816 cases per year S = \$12 H = \$4 per case per year

Range	Price
1 to 49	\$20
50 to 79	18
80 to 99	17
100 or more	16

1. Compute the common EOQ: $= \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(816)12}{4}} = 69.97 \approx 70$ cases
2. The 70 cases can be bought at \$18 per case because 70 falls in the range of 50 to 79 cases. The total cost to purchase 816 cases a year, at the rate of 70 cases per order, will be

$$
\begin{aligned}
TC_{70} &= \text{Carrying cost} + \text{Order cost} + \text{Purchase cost} \\
&= (Q/2)H + (D/Q_0)S + PD \\
&= (70/2)4 + (816/70)12 + 18(816) = \$14{,}968
\end{aligned}
$$

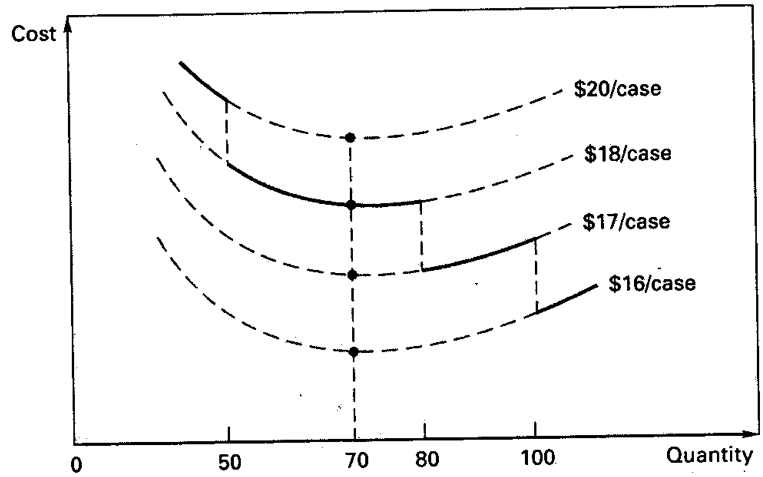


FIGURE 11.10

Total-cost curves for Example 5

Because lower cost ranges exist, each must be checked against the minimum cost generated by 70 cases at $18 each. In order to buy at $17 per case, at least 80 cases must be purchased. (Because the TC curve is rising, 80 cases will have the lowest TC for that curve's feasible region.) The total cost at 80 cases will be

$$TC_{80} = (80/2)4 + (816/80)12 + 17(816) = \$14{,}154$$

To obtain a cost of $16 per case, at least 100 cases per order are required, and the total cost at that price break will be

$$TC_{100} = (100/2)4 + (816/100)12 + 16(816) = \$13{,}354$$

Therefore, because 100 cases per order yields the lowest total cost, 100 cases is the overall optimal order quantity.

When carrying costs are expressed as a percentage of price, determine the best purchase quantity with the following procedure:

1. Beginning with the lowest unit price, compute the minimum points for each price range until you find a feasible minimum point (i.e., until a minimum point falls in the quantity range for its price).
2. If the minimum point for the lowest unit price is feasible, it is the optimal order quantity. If the minimum point is not feasible in the lowest price range, compare the total cost at the price break for all *lower* prices with the total cost of the feasible minimum point. The quantity which yields the lowest total cost is the optimum.

EXAMPLE 6

Surge Electric uses 4,000 toggle switches a year. Switches are priced as follows: 1 to 499, 90 cents each; 500 to 999, 85 cents each; and 1,000 or more, 80 cents each. It costs approximately $30 to prepare an order and receive it, and carrying costs are 40 percent of purchase price per unit on an annual basis. Determine the optimal order quantity and the total annual cost.

SOLUTION

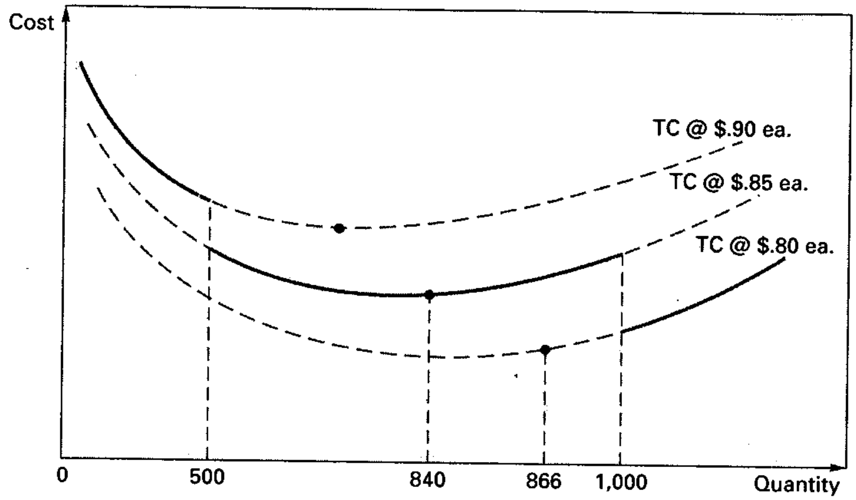
See Figure 11.11:

D = 4,000 switches per year $\quad S = \$30 \quad H = .40P$

Range	Unit Price	*H*
1 to 499	$0.90	.40(0.90) = .36
500 to 999	$0.85	.40(0.85) = .34
1,000 or more	$0.80	.40(0.80) = .32

FIGURE 11.11

Total-cost curves for Example 6.



Find the minimum point for each price, starting with the lowest price, until you locate a feasible minimum point.

$$\text{minimum point}_{0.80} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(4{,}000)30}{.32}} = 866 \text{ switches}$$

Because an order size of 866 switches will cost $0.85 each rather than $0.80 each, 866 is not a feasible minimum point for $0.80 per switch. Next, try $0.85 per unit.

$$\text{minimum point}_{0.85} = \sqrt{\frac{2(4{,}000)30}{.34}} = 840 \text{ switches}$$

This is feasible; it falls in the $0.85 per switch range of 500 to 999.

Now compute the total cost for 840, and compare it to the total cost of the minimum quantity necessary to obtain a price of $0.80 per switch.

$$TC = \text{Carrying costs} + \text{Ordering costs} + \text{Purchasing costs}$$

$$= \left(\frac{Q}{2}\right)H + \left(\frac{D}{Q}\right)S + PD$$

$$TC_{840} = \frac{840}{2}(.34) + \frac{4{,}000}{840}(30) + 0.85(4{,}000) = \$3{,}686$$

$$TC_{1{,}000} = \frac{1{,}000}{2}(.32) + \frac{4{,}000}{1{,}000}(30) + 0.80(4{,}000) = \$3{,}480$$

Thus, the minimum-cost order size is 1,000 switches.

WHEN TO REORDER WITH EOQ ORDERING

reorder point (ROP) When the quantity on hand of an item drops to this amount, the item is reordered.

EOQ models answer the question of how much to order, but not the question of when to order. The latter is the function of models that identify the **reorder point (ROP)** in terms of a *quantity:* The reorder point occurs when the quantity on hand drops to a predetermined amount. That amount generally includes expected demand during lead time and perhaps an extra cushion of stock, which serves to reduce the probability of experiencing a stockout during lead time. Note that in order to know when the reorder point has been reached, a *perpetual* inventory is required.

The goal in ordering is to place an order when the amount of inventory on hand is sufficient to satisfy demand during the time it takes to receive that order (i.e., lead time). There are four determinants of the reorder point quantity:

1. The rate of demand (usually based on a forecast).
2. The lead time.
3. The extent of demand and/or lead time variability.
4. The degree of stockout risk acceptable to management.

Tutorial

If demand and lead time are both constant, the reorder point is simply

$$\text{ROP} = d \times \text{LT} \qquad (11\text{–}10)$$

where

d = Demand rate (units per day or week)

LT = Lead time in days or weeks

Note: Demand and lead time must be expressed in the same time units.

EXAMPLE 7

Tingly takes Two-a-Day vitamins, which are delivered to his home by a routeman seven days after an order is called in. At what point should Tingly reorder?

SOLUTION

$$\begin{aligned} \text{Usage} &= 2 \text{ vitamins a day} \\ \text{Lead time} &= 7 \text{ days} \\ \text{ROP} &= \text{Usage} \times \text{Lead time} \\ &= 2 \text{ vitamins per day} \times 7 \text{ days} = 14 \text{ vitamins} \end{aligned}$$

Thus, Tingly should reorder when 14 vitamin tablets are left.

When variability is present in demand or lead time, it creates the possibility that actual demand will exceed expected demand. Consequently, it becomes necessary to carry additional inventory, called **safety stock,** to reduce the risk of running out of inventory (a stockout) during lead time. The reorder point then increases by the amount of the safety stock:

safety stock Stock that is held in excess of expected demand due to variable demand and/or lead time.

$$\text{ROP} = \begin{matrix}\text{Expected demand} \\ \text{during lead time}\end{matrix} + \text{Safety stock} \qquad (11\text{–}11)$$

For example, if expected demand during lead time is 100 units, and the desired amount of safety stock is 10 units, the ROP would be 110 units.

Figure 11.12 illustrates how safety stock can reduce the risk of a stockout during lead time (LT). Note that stockout protection is needed only during lead time. If there is a sudden surge at any point during the cycle, that will trigger another order. Once that order is received, the danger of an imminent stockout is negligible.

Because it costs money to hold safety stock, a manager must carefully weigh the cost of carrying safety stock against the reduction in stockout risk it provides. The customer *service level* increases as the risk of stockout decreases. Order cycle **service level** can be defined as the probability that demand will not exceed supply during lead time (i.e., that the amount of stock on hand will be sufficient to meet demand). Hence, a service level of 95 percent implies a probability of 95 percent that demand will not exceed supply during lead time. An equivalent statement that demand will be satisfied in 95 percent of such instances does *not* mean that 95 percent of demand will be satisfied. The risk of a stockout is the complement of service level; a customer service level of 95 percent implies a stockout risk of 5 percent. That is,

service level Probability that demand will not exceed supply during lead time.

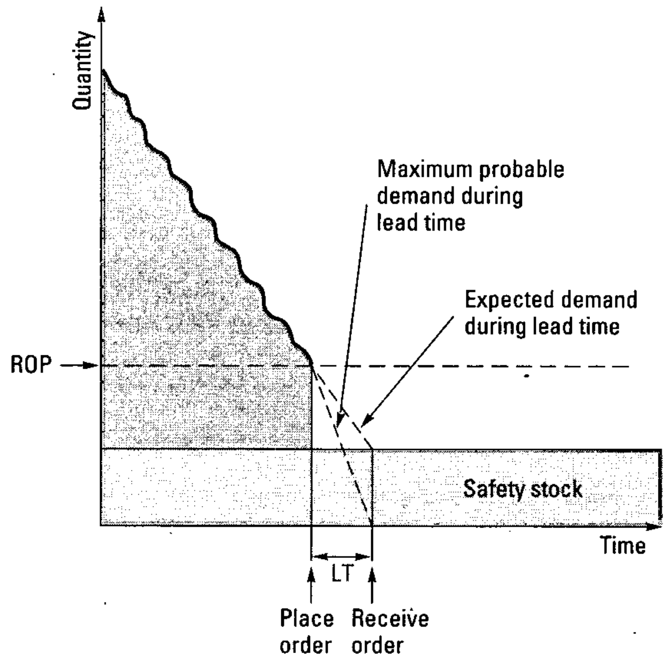
Service level = 100 percent − Stockout risk

Later you will see how the order cycle service level relates to the *annual* service level.

The amount of safety stock that is appropriate for a given situation depends on the following factors:

FIGURE 11.12

Safety stock reduces risk of stockout during lead time



1. The average demand rate and average lead time.
2. Demand and lead time variability.
3. The desired service level.

For a given order cycle service level, the greater the variability in either demand rate or lead time, the greater the amount of safety stock that will be needed to achieve that service level. Similarly, for a given amount of variation in demand rate or lead time, achieving an increase in the service level will require increasing the amount of safety stock. Selection of a service level may reflect stockout costs (e.g., lost sales, customer dissatisfaction) or it might simply be a policy variable (e.g., the manager wants to achieve a specified service level for a certain item).

Let us look at several models that can be used in cases when variability is present. The first model can be used if an estimate of expected demand during lead time and its standard deviation are available. The formula is

$$\text{ROP} = \begin{matrix}\text{Expected demand}\\\text{during lead time}\end{matrix} + z\sigma_{dLT} \tag{11–12}$$

where

z = Number of standard deviations

σ_{dLT} = The standard deviation of lead time demand

The models generally assume that any variability in demand rate or lead time can be adequately described by a normal distribution. However, this is not a strict requirement; the models provide approximate reorder points even where actual distributions depart from normal.

The value of z (see Figure 11.13) used in a particular instance depends on the stockout risk that the manager is willing to accept. Generally, the smaller the risk the manager is willing to accept, the greater the value of z. Use Appendix B, Table B to obtain the value of z, given a desired service level for lead time.

EXAMPLE 8

Suppose that the manager of a construction supply house determined from historical records that demand for sand during lead time averages 50 tons. In addition, suppose the manager determined that demand during lead time could be described by a normal distribution that has a

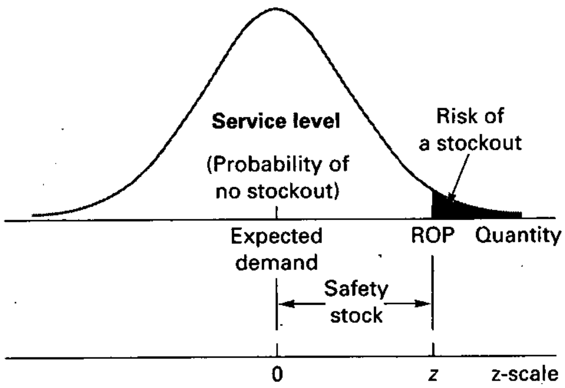


FIGURE 11.13

The ROP based on a normal distribution of lead time demand

mean of 50 tons and a standard deviation of 5 tons. Answer these questions, assuming that the manager is willing to accept a stockout risk of no more than 3 percent:

a. What value of z is appropriate?

b. How much safety stock should be held?

c. What reorder point should be used?

SOLUTION

Expected lead time demand = 50 tons

$\sigma_{dLT} = 5$ tons

Risk = 3 percent

a. From Appendix B, Table B, using a service level of $1 - .03 = .9700$, you obtain a value of $z = +1.88$.

b. Safety stock $= z\sigma_{dLT} = 1.88(5) = 9.40$ tons

c. ROP = Expected lead time demand + Safety stock = 50 + 9.40 = 59.40 tons

When data on lead time demand are not readily available, Formula 11–12 cannot be used. Nevertheless, data are generally available on daily or weekly demand, and on the length of lead time. Using those data, a manager can determine whether demand and/or lead time is variable, if variability exists in one or both, and the related standard deviation(s). For those situations, one of the following formulas can be used:

If only demand is variable, then $\sigma_{dLT} = \sqrt{LT}\sigma_d$, and the reorder point is

$$\text{ROP} = \bar{d} \times \text{LT} + z\sqrt{\text{LT}}\sigma_d \qquad (11\text{–}13)$$

where

$\bar{d}$ = *Average* daily or weekly demand

σ_d = Standard deviation of demand per day or week

LT = Lead time in days or weeks

If only lead time is variable, then $\sigma_{dLT} = d\sigma_{LT}$, and the reorder point is

$$\text{ROP} = d \times \overline{\text{LT}} + zd\sigma_{LT} \qquad (11\text{–}14)$$

where

d = Daily or weekly demand

$\overline{\text{LT}}$ = *Average* lead time in days or weeks

σ_{LT} = Standard deviation of lead time in days or weeks

If both demand and lead time are variable, then

$$\sigma_{dLT} = \sqrt{\overline{LT}\sigma_d^2 + \bar{d}^2\sigma_{LT}^2}$$

and the reorder point is

$$ROP = \bar{d} \times \overline{LT} + z\sqrt{\overline{LT}\sigma_d^2 + \bar{d}^2\sigma_{LT}^2} \quad (11\text{–}15)$$

Note: Each of these models assumes that demand and lead time are *independent.*

EXAMPLE 9

A restaurant uses an average of 50 jars of a special sauce each week. Weekly usage of sauce has a standard deviation of 3 jars. The manager is willing to accept no more than a 10 percent risk of stockout during lead time, which is two weeks. Assume the distribution of usage is normal.

a. Which of the above formulas is appropriate for this situation? Why?

b. Determine the value of z.

c. Determine the ROP.

SOLUTION

$\bar{d}$ = 50 jars per week   LT = 2 weeks

σ_d = 3 jars per week   Acceptable risk = 10 percent, so service level is .90

a. Because only demand is variable (i.e., has a standard deviation), Formula 11–13 is appropriate.

b. From Appendix B, Table B, using a service level of .9000, you obtain $z = +1.28$.

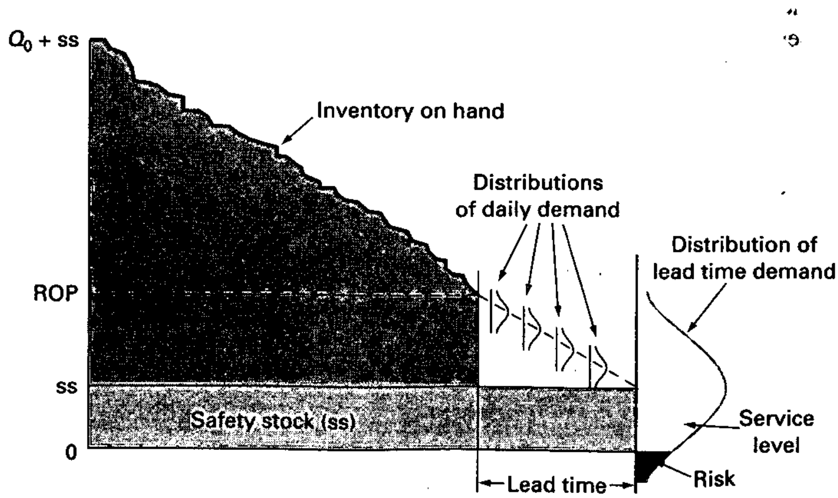
c. $ROP = \bar{d} \times LT + z\sqrt{LT}\sigma_d = 50 \times 2 + 1.28\sqrt{2}(3) = 100 + 5.43 = 105.43$. Because the inventory is discrete units (jars), we round this amount to 106. (Generally, round up.)

Note that a 2-bin ordering system (see p. 487) involves ROP re-ordering: The quantity in the second bin is equal to the ROP.

Comment. The logic of the three formulas for the reorder point may not be immediately obvious. The first part of each formula is the expected demand, which is the product of daily (or weekly) demand and the number of days (or weeks) of lead time. The second part of the formula is z times the standard deviation of lead time demand. For the formula in which only demand is variable, daily (or weekly) demand is assumed to be normally distributed and has the same mean and standard deviation (see Figure 11.14). The standard deviation of demand for the entire lead time is found by summing the *variances* of daily (or weekly) demands, and then finding the square root of that number because, unlike variances, standard deviations are not

FIGURE 11.14

Lead time demand



additive. Hence, if the daily standard deviation is σ_d, the *variance* is σ_d^2, and if lead time is four days, the variance of lead time demand will equal the sum of the 4 variances, which is $4\sigma_d^2$. The standard deviation of lead time demand will be the square root of this, which is equal to $2\sigma_d$. In general, this becomes $\sqrt{LT}\sigma_d$ and, hence, the last part of Formula 11–13.

When only lead time is variable, the explanation is much simpler. The standard deviation of lead time demand is equal to the constant daily demand multiplied by the standard deviation of lead time.

When both demand and lead time are variable, the formula appears truly impressive. However, it is merely the result of squaring the standard deviations of the two previous formulas to obtain their variances, summing them, and then taking the square root.

Shortages and Service Levels

S

The ROP computation does not reveal the expected *amount* of shortage for a given lead time service level. The expected number of units short can, however, be very useful to a manager. This quantity can easily be determined from the same information used to compute the ROP, with one additional piece of information (see Table 11.3). Use of the table assumes that the distribution of lead time demand can be adequately represented by a normal distribution. If it can, the expected number of units short in each order cycle is given by this formula:

$$E(n) = E(z)\sigma_{dLT} \qquad (11\text{–}16)$$

where

$E(n)$ = Expected number of units short per order cycle

$E(z)$ = Standardized number of units short obtained from Table 11.3

σ_{dLT} = Standard deviation of lead time demand

EXAMPLE 10

Suppose the standard deviation of lead time demand is known to be 20 units. Lead time demand is approximately normal.

a. For a lead time service level of 90 percent, determine the expected number of units short for any order cycle.

b. What lead time service level would an expected shortage of 2 units imply?

SOLUTION

σ_{dLT} = 20 units

a. Lead time (cycle) service level = .90. From Table 11.3, $E(z) = 0.048$. Using Formula 11–16, $E(n) = 0.048(20 \text{ units}) = 0.96$, or about 1 unit.

b. For the case where $E(n) = 2$, you must solve for $E(z)$ and then use Table 11.3 to determine the lead time service that implies. Thus, $E(n) = E(z)\sigma_{dLT}$, so $E(z) = E(n)/\sigma_{dLT} = 2/20 = 0.100$. From Table 11.3, this implies a service level of approximately 81.5 percent (interpolating).

The expected number of units short is just that—an expected or *average* amount; the exact number of units short in any given cycle will be an amount close to that. Moreover, if discrete items are involved, the actual number of units short in any cycle will be an integer.

Having determined the expected number of units short for an order cycle, you can determine the expected number of units short per year. It is simply the expected number of units short per cycle multiplied by the number of cycles (orders) per year. Thus,

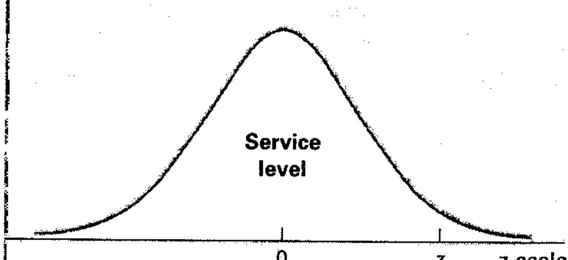
$$E(N) = E(n)\frac{D}{Q} \qquad (11\text{–}17)$$

where

$E(N)$ = Expected number of units short per year

TABLE 11.3 Normal distribution service levels and unit normal loss function

z	Lead Time Service Level	E(z)	z	Lead Time Service Level	E(z)	z	Lead Time Service Level	E(z)	z	Lead Time Service Level	E(z)
−2.40	.0082	2.403	−0.80	.2119	0.920	0.80	.7881	0.120	2.40	.9918	0.003
−2.36	.0091	2.363	−0.76	.2236	0.889	0.84	.7995	0.112	2.44	.9927	0.002
−2.32	.0102	2.323	−0.72	.2358	0.858	0.88	.8106	0.104	2.48	.9934	0.002
−2.28	.0113	2.284	−0.68	.2483	0.828	0.92	.8212	0.097	2.52	.9941	0.002
−2.24	.0125	2.244	−0.64	.2611	0.798	0.96	.8315	0.089	2.56	.9948	0.002
−2.20	.0139	2.205	−0.60	.2743	0.769	1.00	.8413	0.083	2.60	.9953	0.001
−2.16	.0154	2.165	−0.56	.2877	0.740	1.04	.8508	0.077	2.64	.9959	0.001
−2.12	.0170	2.126	−0.52	.3015	0.712	1.08	.8599	0.071	2.68	.9963	0.001
−2.08	.0188	2.087	−0.48	.3156	0.684	1.12	.8686	0.066	2.72	.9967	0.001
−2.04	.0207	2.048	−0.44	.3300	0.657	1.16	.8770	0.061	2.76	.9971	0.001
−2.00	.0228	2.008	−0.40	.3446	0.630	1.20	.8849	0.056	2.80	.9974	0.0008
−1.96	.0250	1.969	−0.36	.3594	0.597	1.24	.8925	0.052	2.84	.9977	0.0007
−1.92	.0274	1.930	−0.32	.3745	0.576	1.28	.8997	0.048	2.88	.9980	0.0006
−1.88	.0301	1.892	−0.28	.3897	0.555	1.32	.9066	0.044	2.92	.9982	0.0005
−1.84	.0329	1.853	−0.24	.4052	0.530	1.36	.9131	0.040	2.96	.9985	0.0004
−1.80	.0359	1.814	−0.20	.4207	0.507	1.40	.9192	0.037	3.00	.9987	0.0004
−1.76	.0392	1.776	−0.16	.4364	0.484	1.44	.9251	0.034	3.04	.9988	0.0003
−1.72	.0427	1.737	−0.12	.4522	0.462	1.48	.9306	0.031	3.08	.9990	0.0003
−1.68	.0465	1.699	−0.08	.4681	0.440	1.52	.9357	0.028	3.12	.9991	0.0002
−1.64	.0505	1.661	−0.04	.4840	0.419	1.56	.9406	0.026	3.16	.9992	0.0002
−1.60	.0548	1.623	0.00	.5000	0.399	1.60	.9452	0.023	3.20	.9993	0.0002
−1.56	.0594	1.586	0.04	.5160	0.379	1.64	.9495	0.021	3.24	.9994	0.0001
−1.52	.0643	1.548	0.08	.5319	0.360	1.68	.9535	0.019	3.28	.9995	0.0001
−1.48	.0694	1.511	0.12	.5478	0.342	1.72	.9573	0.017	3.32	.9995	0.0001
−1.44	.0749	1.474	0.16	.5636	0.324	1.76	.9608	0.016	3.36	.9996	0.0001
−1.40	.0808	1.437	0.20	.5793	0.307	1.80	.9641	0.014	3.40	.9997	0.0001
−1.36	.0869	1.400	0.24	.5948	0.290	1.84	.9671	0.013			
−1.32	.0934	1.364	0.28	.6103	0.275	1.88	.9699	0.012			
−1.28	.1003	1.328	0.32	.6255	0.256	1.92	.9726	0.010			
−1.24	.1075	1.292	0.36	.6406	0.237	1.96	.9750	0.009			
−1.20	.1151	1.256	0.40	.6554	0.230	2.00	.9772	0.008			
−1.16	.1230	1.221	0.44	.6700	0.217	2.04	.9793	0.008			
−1.12	.1314	1.186	0.48	.6844	0.204	2.08	.9812	0.007			
−1.08	.1401	1.151	0.52	.6985	0.192	2.12	.9830	0.006			
−1.04	.1492	1.117	0.56	.7123	0.180	2.16	.9846	0.005			
−1.00	.1587	1.083	0.60	.7257	0.169	2.20	.9861	0.005			
−0.96	.1685	1.049	0.64	.7389	0.158	2.24	.9875	0.004			
−0.92	.1788	1.017	0.68	.7517	0.148	2.28	.9887	0.004			
−0.88	.1894	0.984	0.72	.7642	0.138	2.32	.9898	0.003			
−0.84	.2005	0.952	0.76	.7764	0.129	2.36	.9909	0.003			



EXAMPLE 11

Given the following information, determine the expected number of units short per year.

$D = 1{,}000 \quad Q = 250 \quad E(n) = 2.5$

SOLUTION

Using the formula $E(N) = E(n)\dfrac{D}{Q}$,

$$E(N) = 2.5\left(\frac{1{,}000}{250}\right) = 10.0 \text{ units per year}$$

It is sometimes convenient to think of service level in annual terms. One definition of annual service level is the percentage of demand filled directly from inventory. This is also known as the *fill rate.* Thus, if $D = 1{,}000$, and 990 units were filled directly from inventory (shortages totaling 10 units over the year were recorded), the annual service level (fill rate) would be $990/1{,}000 = 99$ percent. The annual service level and the lead time service level can be related using the following formula:

$$SL_{\text{annual}} = 1 - \frac{E(N)}{D} \qquad (11–18)$$

Using Formulas 11–17 and 11–16,

$$E(N) = E(n)D/Q = E(z)\sigma_{dLT}D/Q$$

Thus,

$$SL_{\text{annual}} = 1 - \frac{E(z)\sigma_{dLT}}{Q} \qquad (11–19)$$

EXAMPLE 12

Given a lead time service level of 90, $D = 1{,}000$, $Q = 250$, and $\sigma_{dLT} = 16$, determine a) the annual service level, and b) the amount of cycle safety stock that would provide an annual service level of .98. From Table 11.3, $E(z) = 0.048$ for a 90 percent lead time service level.

SOLUTION

a. Using Formula 11–19:

$SL_{\text{annual}} = 1 - 0.048(16)/250 = .997$

b. Using Formula 11–19, and an annual service level of .98, solve for $E(z)$:

$.98 = 1 - E(z)(16)/250$

Solving, $E(z) = 0.312$. From Table 11.3, with $E(z) = 0.312$, you can see that this value of $E(z)$ is a little more than the value of 0.307. So it appears that an acceptable value of z might be 0.19. The necessary safety stock to achieve the specified annual service level is equal to $z\sigma_{dLT}$. Hence, the safety stock is $0.19(16) = 3.04$, or approximately 3 units.

Note that in the preceding example, a lead time service level of 90 percent provided an annual service level of 99.7 percent. Naturally, different values of D, Q, and σ_{dLT} will tend to produce different results for a cycle service level of 90 percent. Nonetheless, the annual service level will usually be greater than the cycle service level. In addition, since the annual service level as defined relates to the percentage of units short per year, it makes sense to base cycle service levels on a specified annual service level. This means setting the annual level, using Formula 11–19 to solve for $E(z)$, and then using that value to obtain the service level for the order cycles.

HOW MUCH TO ORDER: FIXED-ORDER-INTERVAL MODEL

The **fixed-order-interval (FOI) model** is used when orders must be placed at fixed time intervals (weekly, twice a month, etc.): The timing of orders is set. The question, then, at each order point, is how much to order. Fixed-interval ordering systems are widely used by retail

fixed-order-interval (FOI) model Orders are placed at fixed time intervals.

businesses. If demand is variable, the order size will tend to vary from cycle to cycle. This is quite different from an EOQ/ROP approach in which the order size generally remains fixed from cycle to cycle, while the length of the cycle varies (shorter if demand is above average, and longer if demand is below average).

Reasons for Using the Fixed-Order-Interval Model

In some cases, a supplier's policy might encourage orders at fixed intervals. Even when that is not the case, grouping orders for items from the same supplier can produce savings in shipping costs. Furthermore, some situations do not readily lend themselves to continuous monitoring of inventory levels. Many retail operations (e.g., drugstores, small grocery stores) fall into this category. The alternative for them is to use fixed-interval ordering, which requires only periodic checks of inventory levels.

Determining the Amount to Order

If both the demand rate and lead time are constant, the fixed-interval model and the fixed-quantity model function identically. The differences in the two models become apparent only when examined under conditions of variability. Like the ROP model, the fixed-interval model can have variations in demand only, in lead time only, or in both demand and lead time. However, for the sake of simplicity and because it is perhaps the most frequently encountered situation, the discussion here will focus only on *variable demand* and *constant lead time.*

Figure 11.15 provides a comparison of the fixed-quantity and fixed-interval systems. In the fixed-quantity arrangement, orders are triggered by a *quantity* (ROP), while in the fixed-interval arrangement orders are triggered by a *time.* Therefore, the fixed-interval system must have stockout protection for lead time plus the next order cycle, but the fixed-quantity system needs protection only during lead time because additional orders can be placed at any time and will be received shortly (lead time) thereafter. Consequently, there is a greater need for safety stock in the fixed-interval model than in the fixed-quantity model. Note, for example, the large dip into safety stock during the second order cycle with the fixed-interval model.

Both models are sensitive to demand experience just prior to reordering, but in somewhat different ways. In the fixed-quantity model, a higher-than-normal demand causes a *shorter time* between orders, whereas in the fixed-interval model, the result is *a larger order size.* Another difference is that the fixed-quantity model requires close monitoring of inventory levels in order to know *when* the amount on hand has reached the reorder point. The fixed-interval model requires only a periodic review (i.e., physical count) of inventory levels just prior to placing an order to determine how much is needed.

Order size in the fixed-interval model is determined by the following computation:

$$\text{Amount to order} = \text{Expected demand during protection interval} + \text{Safety stock} - \text{Amount on hand at reorder time} \quad (11\text{–}20)$$

$$= \bar{d}(\text{OI} + \text{LT}) + z\sigma_d\sqrt{\text{OI} + \text{LT}} - A$$

where

OI = Order interval (length of time between orders)

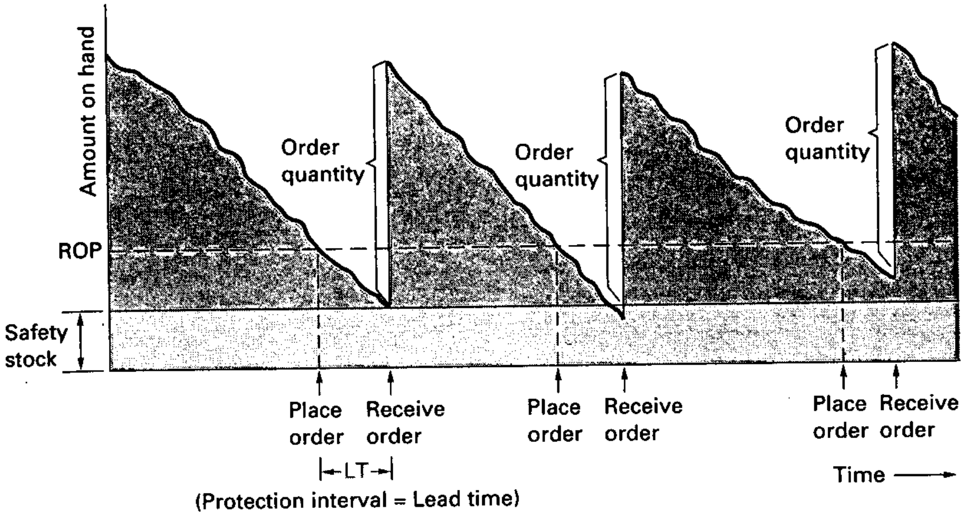
A = Amount on hand at reorder time

As in previous models, we assume that demand during the protection interval is normally distributed.

EXAMPLE 13

Given the following information, determine the amount to order.

$\bar{d}$ = 30 units per day	Desired service level = 99 percent
σ_d = 3 units per day	Amount on hand at reorder time = 71 units
LT = 2 days	OI = 7 days



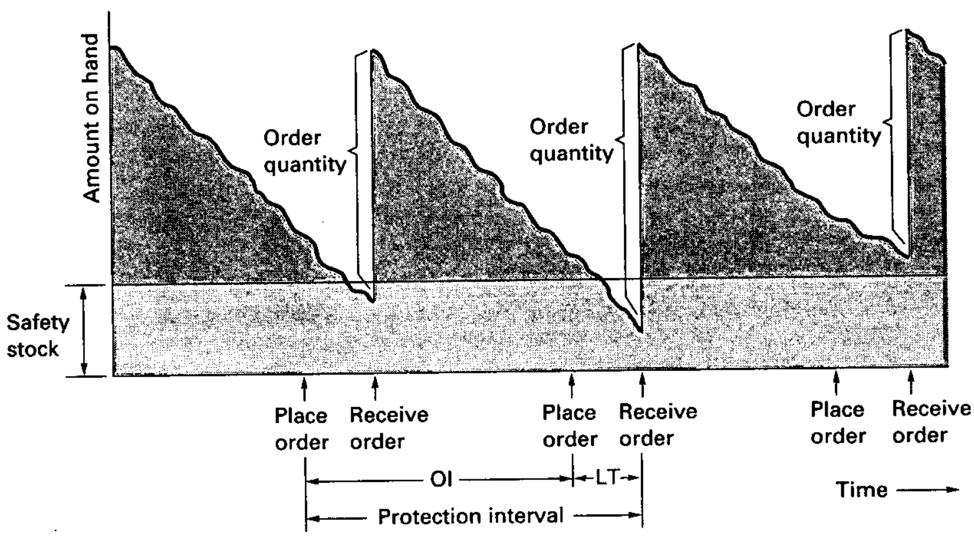


FIGURE 11.15

Comparison of fixed-quantity and fixed-interval ordering

Fixed quantity

Fixed interval

SOLUTION

$z = 2.33$ for 99 percent service level

$$\text{Amount to order} = \bar{d}(\text{OI} + \text{LT}) + z\sigma_d\sqrt{\text{OI} + \text{LT}} - A$$

$$= 30(7 + 2) + 2.33(3)\sqrt{7 + 2} - 71 = 220 \text{ units}$$

An issue related to fixed-interval ordering is the risk of a stockout. From the perspective (i.e., the point in time) of placing an order, there are two points in the order cycle at which a stockout could occur. One is shortly after the order is placed, while waiting to receive the current order (refer to Figure 11.15). The second point is near the end of the cycle, while waiting to receive the next order.

To find the initial risk of a stockout, use the ROP formula (11–13), setting ROP equal to the quantity on hand when the order is placed, and solve for z, then obtain the service level for that value of z from Appendix B, Table B and subtract it from 1.0000 to get the risk of a stockout.

To find the risk of a stockout at the end of the order cycle, use the fixed-interval formula (11–20) and solve for z. Then obtain the service level for that value of z from Appendix B, Table B and subtract it from 1.0000 to get the risk of a stockout.

Let's look at an example.

EXAMPLE 14

Given the following information:

$LT = 4$ days $\quad A = 43$ units
$OI = 12$ days $\quad Q = 171$ units
$\bar{d} = 10$ units/day
$\sigma_d = 2$ units/day

Determine the risk of a stockout at

a. The end of the initial lead time.
b. The end of the second lead time.

SOLUTION

a. For the risk of stockout for the first lead time, we use Formula 11–13. Substituting the given values, we get $43 = 10 \times 4 + z\,(2)(2)$. Solving, $z = +.75$. From Appendix B, Table B, the service level is .7734. The risk is $1 - .7734 = .2266$, which is fairly high.

b. For the risk of a stockout at the end of the second lead time, we use Formula 11–20. Substituting the given values we get $171 = 10 \times (4 + 12) + z\,(2)(4) - 43$. Solving, $z = +6.75$. This value is way out in the right tail of the normal distribution, making the service level virtually 100 percent, and, thus, the risk of a stockout at this point is essentially equal to zero.

Benefits and Disadvantages

The fixed-interval system results in tight control. In addition, when multiple items come from the same supplier, grouping orders can yield savings in ordering, packing, and shipping costs. Moreover, it may be the only practical approach if inventory withdrawals cannot be closely monitored.

On the negative side, the fixed-interval system necessitates a larger amount of safety stock for a given risk of stockout because of the need to protect against shortages during an entire order interval plus lead time (instead of lead time only), and this increases the carrying cost. Also, there are the costs of the periodic reviews.

THE SINGLE-PERIOD MODEL

single-period model Model for ordering of perishables and other items with limited useful lives.

The **single-period model** (sometimes referred to as the *newsboy problem*) is used to handle ordering of perishables (fresh fruits, vegetables, seafood, cut flowers) and items that have a limited useful life (newspapers, magazines, spare parts for specialized equipment). The *period* for spare parts is the life of the equipment, assuming that the parts cannot be used for other equipment. What sets unsold or unused goods apart is that they are not typically carried over from one period to the next, at least not without penalty. Day-old baked goods, for instance, are often sold at reduced prices; leftover seafood may be discarded; and out-of-date magazines may be offered to used book stores at bargain rates. There may even be some cost associated with disposal of leftover goods.

Analysis of single-period situations generally focuses on two costs: shortage and excess. Shortage cost may include a charge for loss of customer goodwill as well as the opportunity cost of lost sales. Generally, **shortage cost** is simply unrealized profit per unit. That is,

shortage cost Generally, the unrealized profit per unit.

$$C_{\text{shortage}} = C_s = \text{Revenue per unit} - \text{Cost per unit}$$

If a shortage or stockout relates to an item used in production or to a spare part for a machine, then shortage cost refers to the actual cost of lost production.

excess cost Difference between purchase cost and salvage value of items left over at the end of a period.

Excess cost pertains to items left over at the end of the period. In effect, excess cost is the difference between purchase cost and salvage value. That is,

$$C_{\text{excess}} = C_e = \text{Original cost per unit} - \text{Salvage value per unit}$$

If there is cost associated with disposing of excess items, the salvage will be negative and will therefore *increase* the excess cost per unit.

The goal of the single-period model is to identify the order quantity, or stocking level, that will minimize the long-run excess and shortage costs.

There are two general categories of problems that we will consider: those for which demand can be approximated using a continuous distribution (perhaps a theoretical one such as a uniform or normal distribution) and those for which demand can be approximated using a discrete distribution (say, historical frequencies or a theoretical distribution such as the Poisson). The kind of inventory can indicate which type of model might be appropriate. For example, demand for petroleum, liquids, and gases tends to vary over some *continuous scale,* thus lending itself to description by a continuous distribution. Demand for tractors, cars, and computers is expressed in terms of the *number of units* demanded and lends itself to description by a discrete distribution.

Continuous Stocking Levels

The concept of identifying an optimal stocking level is perhaps easiest to visualize when demand is *uniform.* Choosing the stocking level is similar to balancing a seesaw, but instead of a person on each end of the seasaw, we have excess cost per unit (C_e) on one end of the distribution and shortage cost per unit (C_s) on the other. The optimal stocking level is analogous to the fulcrum of the seesaw; the stocking level equalizes the cost weights, as illustrated in Figure 11.16.

The *service level* is the *probability* that demand will not exceed the stocking level, and computation of the service level is the key to determining the optimal stocking level, S_o.

$$\text{Service level} = \frac{C_s}{C_s + C_e} \tag{11–21}$$

where

C_s = Shortage cost per unit

C_e = Excess cost per unit

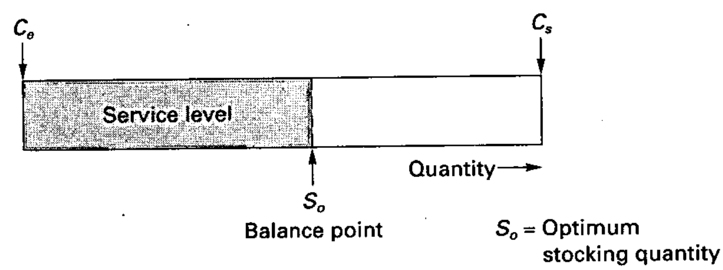


FIGURE 11.16

The optimal stocking level balances unit shortage and excess costs

If actual demand exceeds S_o, there is a shortage; hence, C_s is on the right end of the distribution. Similarly, if demand is less than S_o, there is an excess, so C_e is on the left end of the distribution. When $C_e = C_s$, the optimal stocking level is halfway between the endpoints of the distribution. If one cost is greater than the other, S_o will be closer to the larger cost.

EXAMPLE 15

Sweet cider is delivered weekly to Cindy's Cider Bar. Demand varies uniformly between 300 liters and 500 liters per week. Cindy pays 20 cents per liter for the cider and charges 80 cents per liter for it. Unsold cider has no salvage value and cannot be carried over into the next week due to spoilage. Find the optimal stocking level and its stockout risk for that quantity.

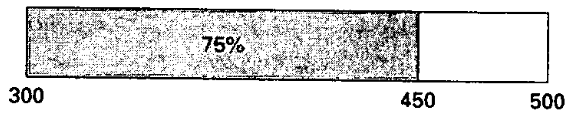
SOLUTION

$$\begin{aligned} C_e &= \text{Cost per unit} - \text{Salvage value per unit} \\ &= \$0.20 - \$0 \\ &= \$0.20 \text{ per unit} \\ C_s &= \text{Revenue per unit} - \text{Cost per unit} \\ &= \$0.80 - \$0.20 \\ &= \$0.60 \text{ per unit} \end{aligned}$$

$$SL = \frac{C_s}{C_s + C_e} = \frac{\$0.60}{\$0.60 + \$0.20} = .75$$

Thus, the optimal stocking level must satisfy demand 75 percent of the time. For the uniform distribution, this will be at a point equal to the minimum demand plus 75 percent of the difference between maximum and minimum demands:

$S_o = 300 + 0.75(500 - 300) = 450$ liters



The stockout risk is $1.00 - 0.75 = 0.25$.

A similar approach applies when demand is normally distributed.

EXAMPLE 16

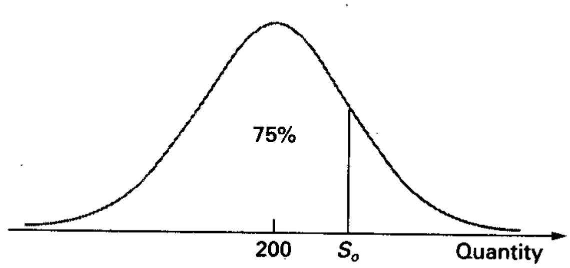
Cindy's Cider Bar also sells a blend of cherry juice and apple cider. Demand for the blend is approximately normal, with a mean of 200 liters per week and a standard deviation of 10 liters per week. $C_s = 60$ cents per liter, and $C_e = 20$ cents per liter. Find the optimal stocking level for the apple-cherry blend.

SOLUTION

$$SL = \frac{C_s}{C_s + C_e} = \frac{\$0.60}{\$0.60 + \$0.20} = .75$$

This indicates that 75 percent of the area under the normal curve must be to the left of the stocking level. Appendix B, Table B shows that a value of z between $+0.67$ and $+0.68$, say, $+0.675$, will satisfy this. The optimal stocking level is $S_o = \text{mean} + z\sigma$. Thus,

$S_o = 200$ liters $+ 0.675(10$ liters$) = 206.75$ liters



Discrete Stocking Levels

When stocking levels are discrete rather than continuous, the service level computed using the ratio $C_s/(C_s + C_e)$ usually does not coincide with a feasible stocking level (e.g., the optimal amount may be *between* five and six units). The solution is to stock at the *next higher level* (e.g., six units). In other words, choose the stocking level so that the desired service level is equaled or *exceeded*. Figure 11.17 illustrates this concept.

The next example illustrates the use of an empirical distribution, followed by an example that illustrates the use of a Poisson distribution.

EXAMPLE 17

Historical records on the use of spare parts for several large hydraulic presses are to serve as an estimate of usage for spares of a newly installed press. Stockout costs involve downtime expenses and special ordering costs. These average \$4,200 per unit short. Spares cost \$800 each, and unused parts have zero salvage. Determine the optimal stocking level.

Number of Spares Used	Relative Frequency	Cumulative Frequency
0	.20	.20
1	.40	.60
2	.30	.90
3	.10	1.00
4 or more	.00	
	1.00	

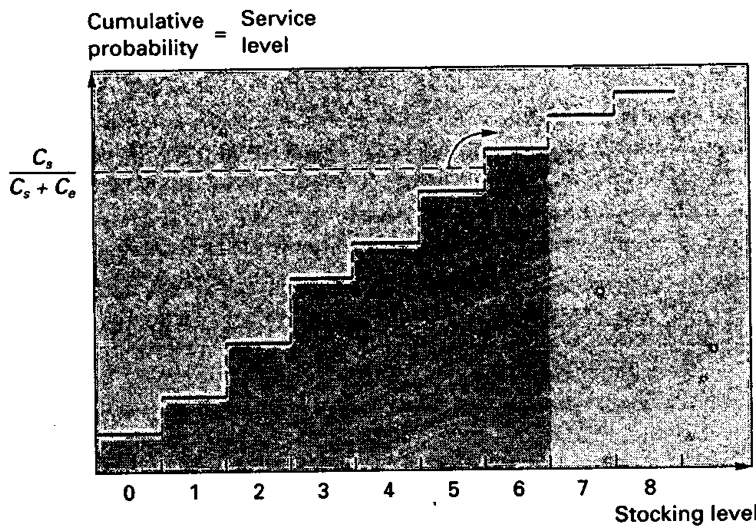


FIGURE 11.17

The service level achievement must equal or exceed the ratio $C_s/C_s + C_e$

SOLUTION

$$C_s = \$4{,}200 \qquad C_e = \$800 \qquad \text{SL} = \frac{C_s}{C_s + C_e} = \frac{\$4{,}200}{\$4{,}200 + \$800} = .84$$

The cumulative-frequency column indicates the percentage of time that demand did not exceed (was equal to or less than) some amount. For example, demand does not exceed one spare 60 percent of the time, or two spares 90 percent of the time. Thus, in order to achieve a service level of *at least* 84 percent, it will be necessary to stock two spares (i.e., to go to the next higher stocking level).

EXAMPLE 18

Demand for long-stemmed red roses at a small flower shop can be approximated using a Poisson distribution that has a mean of four dozen per day. Profit on the roses is \$3 per dozen. Leftover flowers are marked down and sold the next day at a loss of \$2 per dozen. Assume that all marked-down flowers are sold. What is the optimal stocking level?

SOLUTION

$$C_s = \$3 \qquad C_e = \$2 \qquad \text{SL} = \frac{C_s}{C_s + C_e} = \frac{\$3}{\$3 + \$2} = .60$$

Obtain the cumulative frequencies from the Poisson table (Appendix B, Table C) for a mean of 4.0:

Demand (dozen per day)	Cumulative Frequency
0	.018
1	.092
2	.238
3	.434
4	.629
5	.785
⋮	⋮

Compare the service level to the cumulative frequencies. In order to attain a service level of at least .60, it is necessary to stock four dozen.

One final point about discrete stocking levels: If the computed service level is *exactly* equal to the cumulative probability associated with one of the stocking levels, there are *two* equivalent stocking levels in terms of minimizing long-run cost—the one with equal probability and the next higher one. In the preceding example, if the ratio had been equal to .629, we would be indifferent between stocking four dozen and stocking five dozen roses each day.

Operations Strategy

Inventories are a necessary part of doing business, but having too much inventory is not good. One reason is that inventories tend to hide problems; they make it easier to live with problems rather than eliminate them. Another reason is that inventories are costly to maintain. Consequently, a wise operations strategy is to work toward cutting back inventories by (1) reducing lot sizes and (2) reducing safety stocks.

One possibility for reducing the economic order quantity is to work to reduce the ordering cost, S. This might be accomplished by standardized procedures and perhaps by using *electronic data interchange* with suppliers. Another possibility is to examine holding cost, H. If this is understated, using a larger value will reduce the order quantity.

Japanese manufacturers use smaller lot sizes than their Western counterparts because they have a different perspective on inventory carrying costs. In addition to the usual components (e.g., storage, handling, obsolescence), the Japanese recognize the opportunity costs of disrupting the work flow, inability to place machines and workers closer together (which encourages cooperation, socialization, and communication), and hiding problems related to product quality and equipment breakdown. When these are factored in, carrying costs become higher—perhaps much higher—than before, and optimal lot sizes become smaller.

Companies may be able to achieve additional reductions in inventory by reducing the amount of safety stock carried. Important factors in safety stock are lead time and lead time variability, reductions of which will result in lower safety stocks. Firms can often realize these reductions by working with suppliers, choosing suppliers located close to the buyer, and shifting to smaller lot sizes.

The material presented in this chapter focuses primarily on management of *internal* inventories. However, successful inventory management also must include management of *external* inventories (i.e., inventory in the supply chain). Sharing demand data throughout the supply chain can alleviate the unnecessary buildup of safety stock in the supply chain that occurs when information isn't shared. Manufacturers and suppliers can judge the timing of orders from customers, and customers can use information about suppliers' inventories to set reasonable lead times. You will learn more about these possibilities in the chapter on supply chain management.

Last, it is important to make sure that inventory records be kept *accurate* and *up-to-date*. Estimates of holding costs, ordering costs, setup costs, and lead times should be reviewed periodically and updated as necessary.

SUMMARY

Good inventory management is often the mark of a well-run organization. Inventory levels must be planned carefully in order to balance the cost of holding inventory and the cost of providing reasonable levels of customer service. Successful inventory management requires a system to keep track of inventory transactions, accurate information about demand and lead times, realistic estimates of certain inventory-related costs, and a priority system for classifying the items in inventory and allocating control efforts.

Four classes of models are described: EOQ, ROP, fixed-order-interval, and single-period models. The first three are appropriate if unused items can be carried over into subsequent periods. The single-period model is appropriate when items cannot be carried over. EOQ models address the question of how much to order. The ROP models address the question of when to order and are particularly helpful in dealing with situations that include variations in either demand rate or lead time. ROP models involve service level and safety stock considerations. When the time between orders is fixed, the FOI model is useful. The single-period model is used for items that have a "shelf life" of one period. The models presented in this chapter are summarized in Table 11.4 on the next page.

TABLE 11.4 Summary of inventory formulas

Model	Formula		Symbols
1. Basic EOQ	$Q_0 = \sqrt{\frac{2DS}{H}}$	(11–2)	Q_0 = Economic order quantity
	$TC = \frac{Q}{2}H + \frac{D}{Q}S$	(11–1)	D = Annual demand
	Length of order cycle $= \frac{Q_0}{D}$	(11–3)	S = Order cost
			H = Annual carrying cost per unit
2. Economic production quantity	$Q_0 = \sqrt{\frac{2DS}{H}}\sqrt{\frac{p}{p-u}}$	(11–5)	Q_0 = Optimal run or order size
	$TC = \frac{I_{max}}{2}H + \frac{D}{Q}S$	(11–4)	p = Production or delivery rate
	Cycle time $= \frac{Q}{u}$	(11–6)	u = Usage rate
	Run time $= \frac{Q}{p}$	(11–7)	I_{max} = Maximum inventory level
	$I_{max} = \frac{Q_0}{p}(p-u)$	(11–8)	
3. Quantity discounts	$TC = \frac{Q}{2}H + \frac{D}{Q}S + PD$	(11–9)	P = Unit price
4. Reorder point under:			ROP = Quantity on hand at reorder point
a. Constant demand and lead time	$ROP = d(LT)$	(11–10)	d = Demand rate
b. Variable demand rate	$ROP = \bar{d}LT + z\sqrt{LT}(\sigma_d)$	(11–13)	LT = Lead time
c. Variable lead time	$ROP = d\overline{LT} + zd(\sigma_{LT})$	(11–14)	$\bar{d}$ = Average demand rate
d. Variable lead time and demand	$ROP = \bar{d}\overline{LT} + z\sqrt{\overline{LT}\sigma_d^2 + \bar{d}^2\sigma_{LT}^2}$	(11–15)	σ_d = Standard deviation of demand rate
			z = Standard normal deviation
			$\overline{LT}$ = Average lead time
			σ_{LT} = Standard deviation of lead time
5. ROP shortages	$E(n) = E(z)\sigma_{dLT}$	(11–16)	$E(n)$ = Expected number short per cycle
a. Units short per cycle	$E(N) = E(n)\frac{D}{Q}$	(11–17)	$E(z)$ = Standardized number short
b. Units short per year	$SL_{annual} = 1 - \frac{E(z)\sigma_{dLT}}{Q}$	(11–19)	σ_{dLT} = Standard deviation of lead time demand
c. Annual service level			$E(N)$ = Expected number short per year
			SL_{annual} = Annual service level
6. Fixed interval	$Q = \bar{d}(OI + LT) + z\sigma_d\sqrt{OI + LT} - A$	(11–20)	OI = Time between orders
			A = Amount on hand at order time
7. Single period	$SL = \frac{C_s}{C_s + C_e}$	(11–21)	SL = Service level
			C_s = Shortage cost per unit
			C_e = Excess cost per unit

KEY TERMS

A-B-C approach, 490
cycle counting, 491
economic order quantity (EOQ), 492
excess cost, 514
fixed-order-interval (FOI) model, 511
holding (carrying) cost, 489
inventory, 483
inventory turnover, 486
lead time, 489
ordering costs, 489
periodic system, 486
perpetual inventory system, 486
point-of-sale (POS) system, 489
quantity discounts, 499
reorder point (ROP), 504
safety stock, 505

SOLVED PROBLEMS

Problem 1

Basic EOQ. A toy manufacturer uses approximately 32,000 silicon chips annually. The chips are used at a steady rate during the 240 days a year that the plant operates. Annual holding cost is $3 per chip, and ordering cost is $120. Determine:

a. The optimal order quantity.

b. The number of workdays in an order cycle.

Solution

$D = 32{,}000$ chips per year $\quad S = \$120$

$H = \$3$ per unit per year

a. $Q_0 = \sqrt{\dfrac{2DS}{H}} = \sqrt{\dfrac{2(32{,}000)120}{3}} = 1{,}600$ chips.

b. $\dfrac{Q_0}{D} = \dfrac{1{,}600 \text{ chips}}{32{,}000 \text{ chips/yr.}} = \dfrac{1}{20}$ year (i.e., $\frac{1}{20} \times 240$ days), or 12 days.

Problem 2

Economic production quantity. The Dine Corporation is both a producer and a user of brass couplings. The firm operates 220 days a year and uses the couplings at a steady rate of 50 per day. Couplings can be produced at a rate of 200 per day. Annual storage cost is $2 per coupling, and machine setup cost is $70 per run.

a. Determine the economic run quantity.

b. Approximately how many runs per year will there be?

c. Compute the maximum inventory level.

d. Determine the length of the *pure consumption* portion of the cycle.

Solution

$D = 50$ units per day $\times$ 220 days per year $= 11{,}000$ units per year

$S = \$70$

$H = \$2$ per unit per year

$p = 200$ units per day

$u = 50$ units per day

a. $Q_0 = \sqrt{\dfrac{2DS}{H}}\sqrt{\dfrac{p}{p-u}} = \sqrt{\dfrac{2(11{,}000)70}{2}}\sqrt{\dfrac{200}{200-50}} \approx 1{,}013$ units.

b. Number of runs per year: $D/Q_0 = 11{,}000/1{,}013 = 10.86$, or approximately 11.

c. $I_{max} = \dfrac{Q_0}{p}(p-u) = \dfrac{1{,}013}{200}(200-50) = 759.75$ or 760 units.

d. Length of cycle $= \dfrac{Q_0}{u} = \dfrac{1{,}013 \text{ units}}{50 \text{ units per day}} = 20.26$ days

Length of run $= \dfrac{Q_0}{p} = \dfrac{1{,}013 \text{ units}}{200 \text{ units per day}} = 5.065$ days

Length of pure consumption portion = Length of cycle − Length of run

$= 20.26 - 5.065 = 15.20$ days.

Problem 3

Quantity discounts. A small manufacturing firm uses roughly 3,400 pounds of chemical dye a year. Currently the firm purchases 300 pounds per order and pays $3 per pound. The supplier has just announced that orders of 1,000 pounds or more will be filled at a price of $2 per pound. The manufacturing firm incurs a cost of $100 each time it submits an order and assigns an annual holding cost of 17 percent of the purchase price per pound.

a. Determine the order size that will minimize the total cost.

b. If the supplier offered the discount at 1,500 pounds instead of 1,000 pounds, what order size would minimize total cost?

Solution

D = 3,400 pounds per year $\quad S = \$100 \quad H = 0.17P$

a. Compute the EOQ for \$2 per pound:

The quantity ranges are

Range	Unit Price
1 to 999	\$3
1,000+	\$2

$$Q_{\$2/\text{pound}} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(3{,}400)100}{0.17(2)}} = 1{,}414 \text{ pounds}$$

Because this quantity is feasible at \$2 per pound, it is the optimum.

b. When the discount is offered at 1,500 pounds, the EOQ for the \$2 per pound range is no longer feasible. Consequently, it becomes necessary to compute the EOQ for \$3 per pound and compare the total cost for that order size with the total cost using the price break quantity (i.e., 1,500).

$$Q_{\$3/\text{pound}} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(3{,}400)100}{0.17(3)}} \approx 1{,}155 \text{ pounds}$$

$$\text{TC} = \left(\frac{Q}{2}\right)H + \left(\frac{D}{Q}\right)S + PD$$

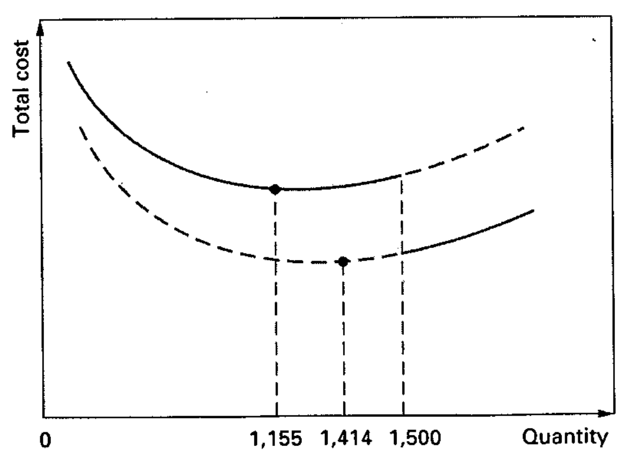
$$\text{TC}_{1,155} = \left(\frac{1{,}155}{2}\right)0.17(3) + \left(\frac{3{,}400}{1{,}155}\right)100 + 3(3{,}400)$$

$$= \$294.53 + \$294.37 + \$10{,}200 = \$10{,}789$$

$$\text{TC}_{1,500} = \left(\frac{1{,}500}{2}\right)0.17(2) + \left(\frac{3{,}400}{1{,}500}\right)100 + 2(3{,}400)$$

$$= \$255 + \$226.67 + \$6{,}800 = \$7{,}282$$

Hence, because it would result in a lower total cost, 1,500 is the optimal order size.



Problem 4

ROP for variable demand and constant lead time. The housekeeping department of a motel uses approximately 400 washcloths per day. The actual number tends to vary with the number of guests on any given night. Usage can be approximated by a normal distribution that has a mean of 400 and a standard deviation of 9 washcloths per day. A linen supply company delivers towels and washcloths with a lead time of three days. If the motel policy is to maintain a stockout risk of 2 percent, what is the minimum number of washcloths that must be on hand at reorder time, and how much of that amount can be considered safety stock?

Solution

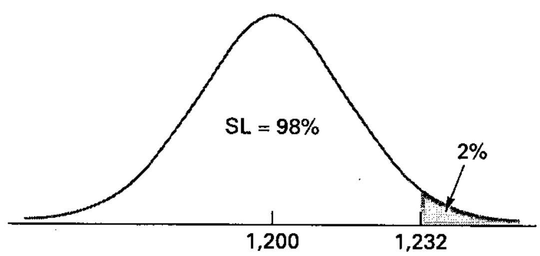
$\bar{d}$ = 400 washcloths per day LT = 3 days

σ_d = 9 washcloths per day Risk = 2 percent, so service level = 98 percent

From Appendix B, Table B, the z value that corresponds to an area under the normal curve to the left of z for 98 percent is about +2.055.

$$\text{ROP} = \bar{d}\text{LT} + z\sqrt{\text{LT}}\sigma_d = 400(3) + 2.055\sqrt{3}(9)$$
$$= 1{,}200 + 32.03, \text{ or approximately } 1{,}232 \text{ washcloths}$$

Safety stock is approximately 32 washcloths.



Problem 5

ROP for constant demand and variable lead time. The motel in the preceding example uses approximately 600 bars of soap each day, and this tends to be fairly constant. Lead time for soap delivery is normally distributed with a mean of six days and a standard deviation of two days. A service level of 90 percent is desired. Find the ROP.

Solution

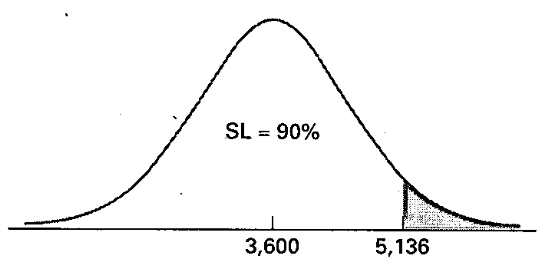
d = 600 bars per day

SL = 90 percent, so z = +1.28 (from Appendix B, Table B)

$\overline{\text{LT}}$ = 6 days

σ_{LT} = 2 days

$$\text{ROP} = d\overline{\text{LT}} + zd(\sigma_{\text{LT}}) = 600(6) + 1.28(600)2$$
$$= 5{,}136 \text{ bars of soap}$$



Problem 6

ROP for variable demand rate and variable lead time. The motel replaces broken glasses at a rate of 25 per day. In the past, this quantity has tended to vary normally and have a standard deviation of 3 glasses per day. Glasses are ordered from a Cleveland supplier. Lead time is normally distributed with an average of 10 days and a standard deviation of 2 days. What ROP should be used to achieve a service level of 95 percent?

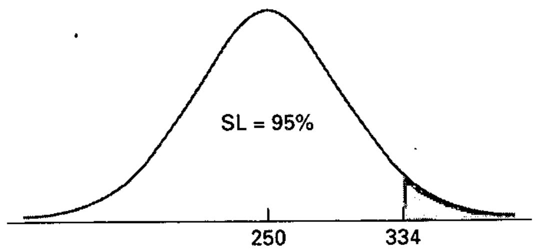
Solution

$\bar{d}$ = 25 glasses per day $\overline{\text{LT}}$ = 10 days

σ_d = 3 glasses per day σ_{LT} = 2 days

SL = 95 percent, so z = + 1.65 (Appendix B, Table B)

$$\text{ROP} = \bar{d}\,\overline{\text{LT}} + z\sqrt{\overline{\text{LT}}\sigma_d^2 + \bar{d}\sigma_{\text{LT}}^2}$$
$$= 25(10) + 1.65\sqrt{10(3)^2 + (25)^2(2)^2} = 334 \text{ glasses}$$



Problem 7

Shortages and service levels. The manager of a store that sells office supplies has decided to set an annual service level of 96 percent for a certain model of telephone answering equipment. The store sells approximately 300 of this model a year. Holding cost is \$5 per unit annually, ordering cost is \$25, and $\sigma_{dLT} = 7$.

a. What average number of units short per year will be consistent with the specified annual service level?

b. What average number of units short per cycle will provide the desired annual service level?

c. What lead time service level is necessary for the 96 percent annual service level?

Solution

$SL_{annual} = 96$ percent $\quad D = 300$ units $\quad H = \$5 \quad S = \$25 \quad \sigma_{dLT} = 7$

a. $E(N) = (1 - SL_{annual})\,D = (1 - .96)(300) = 12$ units

b. $E(N) = E(n)\frac{D}{Q}$. Solving for $E(n)$, you have

$$E(n) = E(N) \div \left(\frac{D}{Q}\right) = 12 \div \left(\frac{300}{Q}\right)$$

$$Q = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(300)(25)}{5}} = 54.77 \text{ (round to 55)}$$

Then $E(n) = 12 \div \left(\frac{300}{55}\right) = 2.2$.

c. In order to find the lead time service level, you need the value of $E(z)$. Because the value of $E(n)$ is 2.2 and $E(n) = E(z)\sigma_{dLT}$, you have $2.2 = E(z)(7)$. Solving gives $E(z) = 2.2 \div 7 = 0.314$. Interpolating in Table 11.3 gives the approximate lead time service level. Thus,

$$\frac{0.307 - 0.314}{0.307 - 0.324} = \frac{.5793 - x}{.5793 - .5636}$$

Solving,

$x = .5728$

[To interpolate, find the two values between which the computed number falls in the $E(z)$ column. Then find the difference between the computed value and one end of the range, and divide by the difference between the two ends of the range. Perform the corresponding calculation on the two service levels using x for the unknown value, and solve for x. Often, simply "eyeballing" the unknown value will suffice.]

Problem 8

Fixed-order-interval model. A lab orders a number of chemicals from the same supplier every 30 days. Lead time is five days. The assistant manager of the lab must determine how much of one of these chemicals to order. A check of stock revealed that eleven 25-ml jars are on hand. Daily usage of the chemical is approximately normal with a mean of 15.2 ml per day and a standard deviation of 1.6 ml per day. The desired service level for this chemical is 95 percent.

a. How many jars of the chemical should be ordered?

b. What is the average amount of safety stock of the chemical?

Solution

$\bar{d} = 15.2$ ml per day	OI = 30 days	SL = 95% requires $z = 1.65$
$\sigma_d = 1.6$ ml per day	LT = 5 days	A = 11 jars × 25 ml per jar = 275 ml

a. $\text{Amount to order} = \bar{d}(\text{OI} + \text{LT}) + z\sigma_d\sqrt{\text{OI} + \text{LT}} - A$

$$= 15.2(30 + 5) + 1.65(1.6)\sqrt{30 + 5} - 275 = 272.62 \text{ ml}$$

Convert this to number of jars:

$$\frac{272.62 \text{ ml}}{25 \text{ ml per jar}} = 10.90 \text{ or } 11 \text{ jars}$$

b. Safety stock $= z\sigma_d\sqrt{\text{OI} + \text{LT}} = 1.65(1.6)\sqrt{30 + 5} = 15.62$ ml.

Problem 9

Single-period model. A firm that installs cable TV systems uses a certain piece of equipment for which it carries two spare parts. The parts cost $500 each and have no salvage value. Part failures can be modeled by a Poisson distribution with a mean of two failures during the useful life of the equipment. Holding and disposal costs are negligible. Estimate the apparent range of shortage cost.

Solution

C_s is unknown $\quad C_e = \$500$

The Poisson table (Appendix B, Table C) provides these values for a mean of 2.0:

Number of Failures	Cumulative Probability
0	.135
1	.406
2	.677
3	.857
4	.947
5	.983
⋮	⋮

For the optimal stocking level, the service level must usually be rounded up to a feasible stocking level. Hence, you know that the service level must have been between .406 and .677 in order to make two units the optimal level. By setting the service level equal first to .406 and then to .677, you can establish bounds on the possible range of shortage costs.

$$\frac{C_s}{C_s + \$500} = .406, \text{ so } C_s = .406(\$500 + C_s)$$

Solving, you find $C_s = \$341.75$.
Similarly,

$$\frac{C_s}{C_s + \$500} = .677, \text{ so } C_s = .677(\$500 + C_s)$$

Solving, you find $C_s = \$1{,}047.99$. Hence, the apparent range of shortage cost is $341.75 to $1,047.99.

DISCUSSION AND REVIEW QUESTIONS

1. What are the primary reasons for holding inventory?
2. What are the requirements for effective inventory management?
3. Briefly describe each of the costs associated with inventory.
4. What potential benefits and risks do RFID chip tags have for inventory management?
5. Why might it be inappropriate to use inventory turnover ratios to compare inventory performance of companies that are in different industries?
6. List the major assumptions of the EOQ model.
7. How would you respond to the criticism that EOQ models tend to provide misleading results because values of *D, S,* and *H* are, at best, educated guesses?
8. Explain briefly how a higher carrying cost can result in a decrease in inventory.
9. What is safety stock, and what is its purpose?

10. Under what circumstances would the amount of safety stock held be
    a. Large? *b.* Small? *c.* Zero?
11. What is meant by the term *service level*? Generally speaking, how is service level related to the amount of safety stock held?
12. Describe briefly the A-B-C approach to inventory control.
13. The purchasing agent for a company that assembles and sells air-conditioning equipment in a Latin American country has noted that the cost of compressors has increased significantly each time they have reordered. The company uses an EOQ model to determine order size. What are the implications of this price escalation with respect to order size? What factors other than price must be taken into consideration?
14. Explain how a decrease in setup time can lead to a decrease in the average amount of inventory a firm holds, and why that would be beneficial.
15. What is the single-period model, and under what circumstances is it appropriate?
16. Can the optimal stocking level in the single-period model ever be less than expected demand? Explain briefly.
17. What are some ways that a company can reduce the need for inventories?

TAKING STOCK

1. What trade-offs are involved in each of these aspects of inventory management?
   a. Buying additional amounts to take advantage of quantity discounts.
   b. Treating holding cost as a percentage of unit price instead of as a constant amount.
   c. Conducting cycle counts once a quarter instead of once a year.
2. Who needs to be involved in inventory decisions involving holding costs? Setting inventory levels? Quantity discount purchases?
3. How has technology aided inventory management? How have technological improvements in products such as automobiles and computers impacted inventory decisions?

CRITICAL THINKING EXERCISE

To be competitive, many fast-food chains began to expand their menus to include a wider range of foods. Although contributing to competitiveness, this has added to the complexity of operations, including inventory management. Specifically, in what ways does the expansion of menu offerings create problems for inventory management?

PROBLEMS

1. The manager of an automobile repair shop hopes to achieve a better allocation of inventory control efforts by adopting an A-B-C approach to inventory control. Given the monthly usages in the following table, classify the items in A, B, and C categories according to dollar usage.

Item	Usage	Unit Cost
4021.....	50	$1,400
9402.....	300	12
4066.....	40	700
6500.....	150	20
9280.....	10	1,020
4050.....	80	140
6850.....	2,000	15
3010.....	400	20
4400.....	7,000	5

2. The following table contains figures on the monthly volume and unit costs for a random sample of 16 items from a list of 2,000 inventory items at a health care facility.

Item	Unit Cost	Usage
K34	10	200
K35	25	600
K36	36	150
M10	16	25
M20	20	80

Item	Unit Cost	Usage
Z45	80	200
F14	20	300
F95	30	800
F99	20	60
D45	10	550
D48	12	90
D52	15	110
D57	40	120
N08	30	40
P05	16	500
P09	10	30

a. Develop an A-B-C classification for these items.
b. How could the manager use this information?
c. After reviewing your classification scheme, suppose that the manager decides to place item P05 into the A category. What are some possible explanations for this decision?

3. A large bakery buys flour in 25-pound bags. The bakery uses an average of 4,860 bags a year. Preparing an order and receiving a shipment of flour involves a cost of $10 per order. Annual carrying costs are $75 per bag.
   a. Determine the economic order quantity.
   b. What is the average number of bags on hand?
   c. How many orders per year will there be?
   d. Compute the total cost of ordering and carrying flour.
   e. If ordering costs were to increase by $1 per order, how much would that affect the minimum total annual cost?
4. A large law firm uses an average of 40 boxes of copier paper a day. The firm operates 260 days a year. Storage and handling costs for the paper are $30 a year per box, and it costs approximately $60 to order and receive a shipment of paper.
   a. What order size would minimize the sum of annual ordering and carrying costs?
   b. Compute the total annual cost using your order size from part *a.*
   c. Except for rounding, are annual ordering and carrying costs always equal at the EOQ?
   d. The office manager is currently using an order size of 200 boxes. The partners of the firm expect the office to be managed "in a cost-efficient manner." Would you recommend that the office manager use the optimal order size instead of 200 boxes? Justify your answer.
5. Garden Variety Flower Shop uses 750 clay pots a month. The pots are purchased at $2 each. Annual carrying costs per pot are estimated to be 30 percent of cost, and ordering costs are $20 per order. The manager has been using an order size of 1,500 flower pots.
   a. What additional annual cost is the shop incurring by staying with this order size?
   b. Other than cost savings, what benefit would using the optimal order quantity yield?
6. A produce distributor uses 800 packing crates a month, which it purchases at a cost of $10 each. The manager has assigned an annual carrying cost of 35 percent of the purchase price per crate. Ordering costs are $28. Currently the manager orders once a month. How much could the firm save annually in ordering and carrying costs by using the EOQ?
7. A manager receives a forecast for next year. Demand is projected to be 600 units for the first half of the year and 900 units for the second half. The monthly holding cost is $2 per unit, and it costs an estimated $55 to process an order.
   a. Assuming that monthly demand will be level during each of the six-month periods covered by the forecast (e.g., 100 per month for each of the first six months), determine an order size that will minimize the sum of ordering and carrying costs for each of the six-month periods.
   b. Why is it important to be able to assume that demand will be level during each six-month period?
   c. If the vendor is willing to offer a discount of $10 *per order* for ordering in multiples of 50 units (e.g., 50, 100, 150), would you advise the manager to take advantage of the offer in either period? If so, what order size would you recommend?

8. A food processor uses approximately 27,000 glass jars a month for its fruit juice product. Because of storage limitations, a lot size of 4,000 jars has been used. Monthly holding cost is 18 cents per jar, and reordering cost is $60 per order. The company operates an average of 20 days a month.
   a. What penalty is the company incurring by its present order size?
   b. The manager would prefer ordering 10 times each month but would have to justify any change in order size. One possibility is to simplify order processing to reduce the ordering cost. What ordering cost would enable the manager to justify ordering every other day?
   c. Suppose that after investigating ordering cost, the manager is able to reduce it to $50. How else could the manager justify using an order size that would be consistent with ordering every other day?
9. The Friendly Sausage Factory (FSF) can produce hot dogs at a rate of 5,000 per day. FSF supplies hot dogs to local restaurants at a steady rate of 250 per day. The cost to prepare the equipment for producing hot dogs is $66. Annual holding costs are 45 cents per hot dog. The factory operates 300 days a year. Find
   a. The optimal run size.
   b. The number of runs per year.
   c. The length (in days) of a run.
10. A chemical firm produces sodium bisulfate in 100-pound bags. Demand for this product is 20 tons per day. The capacity for producing the product is 50 tons per day. Setup costs $100, and storage and handling costs are $5 per ton a year. The firm operates 200 days a year. (Note: 1 ton = 2,000 pounds.)
    a. How many bags per run are optimal?
    b. What would the average inventory be for this lot size?
    c. Determine the approximate length of a production run, in days.
    d. About how many runs per year would there be?
    e. How much could the company save annually if the setup cost could be reduced to $25 per run?
11. A company is about to begin production of a new product. The manager of the department that will produce one of the components for the product wants to know how often the machine used to produce the item will be available for other work. The machine will produce the item at a rate of 200 units a day. Eighty units will be used daily in assembling the final product. Assembly will take place five days a week, 50 weeks a year. The manager estimates that it will take almost a full day to get the machine ready for a production run, at a cost of $300. Inventory holding costs will be $10 a year.
    a. What run quantity should be used to minimize total annual costs?
    b. What is the length of a production run in days?
    c. During production, at what rate will inventory build up?
    d. If the manager wants to run another job between runs of this item, and needs a minimum of 10 days per cycle for the other work, will there be enough time?
12. A company manufactures hair dryers. It buys some of the components, but it makes the heating element, which it can produce at the rate of 800 per day. Hair dryers are assembled daily, 250 days a year, at a rate of 300 per day. Because of the disparity between the production and usage rates, the heating elements are periodically produced in batches of 2,000 units.
    a. Approximately how many *batches* of heating elements are produced annually?
    b. If production on a batch begins when there is no inventory of heating elements on hand, how much inventory will be on hand *two days later?*
    c. What is the average inventory of elements, assuming each production cycle begins when there are none on hand?
    d. The same equipment that is used to make the heating elements could also be used to make a component for another of the firm's products. That job would require four days, including setup. Setup time for making a batch of the heating elements is a half day. Is there enough time to do this job between production of batches of heating elements? Explain.
13. A mail-order house uses 18,000 boxes a year. Carrying costs are 60 cents per box a year, and ordering costs are $96. The following price schedule applies. Determine:
    a. The optimal order quantity.
    b. The number of orders per year.

Number of Boxes	Price per Box
1,000 to 1,999	$1.25
2,000 to 4,999	1.20
5,000 to 9,999	1.15
10,000 or more	1.10

14. A jewelry firm buys semiprecious stones to make bracelets and rings. The supplier quotes a price of \$8 per stone for quantities of 600 stones or more, \$9 per stone for orders of 400 to 599 stones, and \$10 per stone for lesser quantities. The jewelry firm operates 200 days per year. Usage rate is 25 stones per day, and ordering costs are \$48.
    a. If carrying costs are \$2 per year for each stone, find the order quantity that will minimize total annual cost.
    b. If annual carrying costs are 30 percent of unit cost, what is the optimal order size?
    c. If lead time is six working days, at what point should the company reorder?
15. A manufacturer of exercise equipment purchases the pulley section of the equipment from a supplier who lists these prices: less than 1,000, \$5 each; 1,000 to 3,999, \$4.95 each; 4,000 to 5,999, \$4.90 each; and 6,000 or more, \$4.85 each. Ordering costs are \$50, annual carrying costs per unit are 40 percent of purchase cost, and annual usage is 4,900 pulleys. Determine an order quantity that will minimize total cost.
16. A company will begin stocking remote control devices. Expected monthly demand is 800 units. The controllers can be purchased from either supplier A or supplier B. Their price lists are as follows:

SUPPLIER A		SUPPLIER B	
Quantity	**Unit Price**	**Quantity**	**Unit Price**
1–199	\$14.00	1–149	\$14.10
200–499	13.80	150–349	13.90
500+	13.60	350+	13.70

    Ordering cost is \$40 and annual holding cost is 25 percent of unit price per unit. Which supplier should be used and what order quantity is optimal if the intent is to minimize total annual costs?
17. A manager just received a new price list from a supplier. It will now cost \$1.00 a box for order quantities of 801 or more boxes, \$1.10 a box for 200 to 800 boxes, and \$1.20 a box for smaller quantities. Ordering cost is \$80 per order and carrying costs are \$10 per box a year. The firm uses 3,600 boxes a year. The manager has suggested a "round number" order size of 800 boxes. The manager's rationale is that with a U-shaped cost curve that is fairly flat at its minimum, the difference in total annual cost between 800 and 801 units would be small anyway. How would you reply to the manager's suggestion? What order size would you recommend?
18. A newspaper publisher uses roughly 800 feet of baling wire each day to secure bundles of newspapers while they are being distributed to carriers. The paper is published Monday through Saturday. Lead time is six workdays. What is the appropriate reorder point quantity, given that the company desires a service level of 95 percent, if that stockout risk for various levels of safety stock are as follows: 1,500 feet, 0.10; 1,800 feet, 0.05; 2,100 feet, 0.02; and 2,400 feet, 0.01?
19. Given this information:

    Expected demand during lead time = 300 units

    Standard deviation of lead time demand = 30 units

    Determine each of the following, assuming that lead time demand is distributed normally:
    a. The ROP that will provide a risk of stockout of 1 percent during lead time.
    b. The safety stock needed to attain a 1 percent risk of stockout during lead time.
    c. Would a stockout risk of 2 percent require more or less safety stock than a 1 percent risk? Explain. Would the ROP be larger, smaller, or unaffected if the acceptable risk was 2 percent instead of 1 percent? Explain.
20. Given this information:

    Lead-time demand = 600 pounds

    Standard deviation of lead-time demand = 52 pounds (Assume normality.)

    Acceptable stockout risk during lead time = 4 percent
    a. What amount of safety stock is appropriate?
    b. When should this item be reordered?
21. Demand for walnut fudge ice cream at the Sweet Cream Dairy can be approximated by a normal distribution with a mean of 21 gallons per week and a standard deviation of 3.5 gallons per week. The new manager desires a service level of 90 percent. Lead time is two days, and the dairy is open seven days a week. (Hint: Work in terms of weeks.)

a. If an ROP model is used, what ROP would be consistent with the desired service level?

b. If a fixed-interval model is used instead of an ROP model, what order size would be needed for the 90 percent service level with an order interval of 10 days and a supply of 8 gallons on hand at the order time? What is the probability of experiencing a stockout before this order arrives?

c. Suppose the manager is using the ROP model described in part *a*. One day after placing an order with the supplier, the manager receives a call from the supplier that the order will be delayed because of problems at the supplier's plant. The supplier promises to have the order there in two days. After hanging up, the manager checks the supply of walnut fudge ice cream and finds that 2 gallons have been sold since the order was placed. Assuming the supplier's promise is valid, what is the probability that the dairy will run out of this flavor before the shipment arrives?

22. The injection molding department of a company uses an average of 30 gallons of special lubricant a day. The supply of the lubricant is replenished when the amount on hand is 170 gallons. It takes four days for an order to be delivered. Safety stock is 50 gallons, which provides a stockout risk of 9 percent. What amount of safety stock would provide a stockout risk of 3 percent? Assume normality.

23. A company uses 85 circuit boards a day in a manufacturing process. The person who orders the boards follows this rule: Order when the amount on hand drops to 625 boards. Orders are delivered approximately six days after being placed. The delivery time is normal with a mean of six days and a standard deviation of 1.10 days. What is the probability that the supply of circuit boards will be exhausted before the order is received if boards are reordered when the amount on hand drops to 625 boards?

24. One item a computer store sells is supplied by a vendor who handles only that item. Demand for that item recently changed, and the store manager must determine when to replenish it. The manager wants a probability of at least 96 percent of not having a stockout during lead time. The manager expects demand to average a dozen units a day and have a standard deviation of 2 units a day. Lead time is variable, averaging four days with a standard deviation of one day. Assume normality and that seasonality is not a factor.

    a. When should the manager reorder to achieve the desired probability?

    b. Why might the model not be appropriate if seasonality was present?

25. The manager of a car wash received a revised price list from the vendor who supplies soap, and a promise of a shorter lead time for deliveries. Formerly the lead time was four days, but now the vendor promises a reduction of 25 percent in that time. Annual usage of soap is 4,500 gallons. The car wash is open 360 days a year. Assume that daily usage is normal, and that it has a standard deviation of 2 gallons per day. The ordering cost is $30 and annual carrying cost is $3 a gallon. The revised price list (cost per gallon) is shown in the table.

Quantity	Unit Price
1–399	$2.00
400–799	1.70
800+	1.62

    a. What order quantity is optimal?

    b. What ROP is appropriate if the acceptable risk of a stockout is 1.5 percent?

26. A small copy center uses five 500-sheet boxes of copy paper a week. Experience suggests that usage can be well approximated by a normal distribution with a mean of five boxes per week and a standard deviation of one-half box per week. Two weeks are required to fill an order for letterhead stationery. Ordering cost is $2, and annual holding cost is 20 cents per box.

    a. Determine the economic order quantity, assuming a 52-week year.

    b. If the copy center reorders when the supply on hand is 12 boxes, compute the risk of a stockout.

    c. If a fixed interval of seven weeks instead of an ROP is used for reordering, what risk does the copy center incur that it will run out of stationery before this order arrives if it orders 36 boxes when the amount on hand is 12 boxes?

27. Ned's Natural Foods sells unshelled peanuts by the pound. Historically, Ned has observed that daily demand is normally distributed with a mean of 80 pounds and a standard deviation of 10 pounds. Lead time also appears normally distributed with a mean of eight days and a standard deviation of one day.

    a. What ROP would provide a stockout risk of 10 percent during lead time?

    b. What is the expected number of units (pounds) short per cycle?

28. Regional Supermarket is open 360 days per year. Daily use of cash register tape averages 10 rolls. Usage appears normally distributed with a standard deviation of 2 rolls per day. The cost of ordering tape is $1, and carrying costs are 40 cents per roll a year. Lead time is three days.

a. What is the EOQ?
b. What ROP will provide a lead time service level of 96 percent?
c. What is the expected number of units short per cycle with 96 percent? Per year?
d. What is the annual service level?

29. A service station uses 1,200 cases of oil a year. Ordering cost is $40, and annual carrying cost is $3 per case. The station owner has specified an *annual* service level of 99 percent.
a. What level of safety stock is appropriate if lead time demand is normally distributed with a mean of 80 cases and a standard deviation of 5 cases?
b. What is the risk of a stockout during lead time?

30. Weekly demand for diesel fuel at a department of parks depot is 250 gallons. The depot operates 52 weeks a year. Weekly usage is normal and has a standard deviation of 14 gallons. Holding cost for the fuel is $1 a month, and it costs $20 in administrative time to submit an order for more fuel. It takes one-half week to receive a delivery of diesel fuel. Determine the amount of safety stock that would be needed if the manager wants
a. An annual service level of 98 percent. What is the implication of negative safety stock?
b. The expected number of units short per order cycle to be no more than 5 gallons.

31. A drugstore uses fixed-order cycles for many of the items it stocks. The manager wants a service level of .98. Determine the order size that will be consistent with this service level for the items in the table for an order interval of 14 days and a lead time of 2 days:

Item	Average Daily Demand	Standard Deviation	Quantity on Hand
K033	60	5	420
K144	50	4	375
L700	8	2	160

32. A manager must set up inventory ordering systems for two new production items, P34 and P35. P34 can be ordered at any time, but P35 can be ordered only once every four weeks. The company operates 50 weeks a year, and the weekly usage rates for both items are normally distributed. The manager has gathered the following information about the items:

	Item P34	Item P35
Average weekly demand	60 units	70 units
Standard deviation	4 units per week	5 units per week
Unit cost	$15	$20
Annual holding cost	30%	30%
Ordering cost	$70	$30
Lead time	2 weeks	2 weeks
Acceptable stockout risk	2.5%	2.5%

a. When should the manager reorder each item?
b. Compute the order quantity for P34.
c. Compute the order quantity for P35 if 110 units are on hand at the time the order is placed.

33. Given the following list of items,
a. Classify the items as A, B, or C.
b. Determine the economic order quantity for each item (round to the nearest whole unit).

Item	Estimated Annual Demand	Ordering Cost	Holding Cost (%)	Unit Price
H4-010	20,000	50	20	2.50
H5-201	60,200	60	20	4.00
P6-400	9,800	80	30	28.50
P6-401	14,500	50	30	12.00
P7-100	6,250	50	30	9.00
P9-103	7,500	50	40	22.00
TS-300	21,000	40	25	45.00

TS-400	45,000	40	25	40.00
TS-041	800	40	25	20.00
V1-001	33,100	25	35	4.00

34. Demand for jelly doughnuts on Saturdays at Don's Doughnut Shoppe is shown in the following table. Determine the optimal number of doughnuts, in dozens, to stock if labor, materials, and overhead are estimated to be $3.20 per dozen, doughnuts are sold for $4.80 per dozen, and leftover doughnuts at the end of each day are sold the next day at half price. What is the *resulting* service level?

Demand (dozens)	Relative Frequency
19	.01
20	.05
21	.12
22	.18
23	.13
24	.14
25	.10
26	.11
27	.10
28	.04
29	.02

35. A public utility intends to buy a turbine as part of an expansion plan and must now decide on the number of spare parts to order. One part, no. X135, can be purchased for $100 each. Carrying and disposal costs are estimated to be 145 percent of the purchase price over the life of the turbine. A stockout would cost roughly $88,000 due to downtime, ordering, and "special purchase" factors. Historical records based on the performance of similar equipment operating under similar conditions suggest that demand for spare parts will tend to approximate a Poisson distribution with a mean of 3.2 parts for the useful life of the turbine.
    a. What is the optimal number of spares to order?
    b. Carrying no spare parts would be the best strategy for what range of shortage cost?
36. Skinner's Fish Market buys fresh Boston bluefish daily for $4.20 per pound and sells it for $5.70 per pound. At the end of each business day, any remaining bluefish is sold to a producer of cat food for $2.40 per pound. Daily demand can be approximated by a normal distribution with a mean of 80 pounds and a standard deviation of 10 pounds. What is the optimal stocking level?
37. A small grocery store sells fresh produce, which it obtains from a local farmer. During the strawberry season, demand for fresh strawberries can be reasonably approximated using a normal distribution with a mean of 40 quarts per day and a standard deviation of 6 quarts per day. Excess costs run 35 cents per quart. The grocer orders 49 quarts per day.
    a. What is the implied cost of shortage per quart?
    b. Why might this be a reasonable figure?
38. Demand for devil's food whipped-cream layer cake at a local pastry shop can be approximated using a Poisson distribution with a mean of six per day. The manager estimates it costs $9 to prepare each cake. Fresh cakes sell for $12. Day-old cakes sell for $9 each. What stocking level is appropriate if one-half of the day-old cakes are sold and the rest thrown out?
39. Burger Prince buys top-grade ground beef for $1.00 per pound. A large sign over the entrance guarantees that the meat is fresh daily. Any leftover meat is sold to the local high school cafeteria for 80 cents per pound. Four hamburgers can be prepared from each pound of meat. Burgers sell for 60 cents each. Labor, overhead, meat, buns, and condiments cost 50 cents per burger. Demand is normally distributed with a mean of 400 pounds per day and a standard deviation of 50 pounds per day. What daily order quantity is optimal? (Hint: Shortage cost must be in dollars per pound.)
40. Demand for rug-cleaning machines at Clyde's U-Rent-It is shown in the following table. Machines are rented by the day only. Profit on the rug cleaners is $10 per day. Clyde has four rug-cleaning machines.

Demand	Frequency
0	.30
1	.20
2	.20
3	.15
4	.10
5	.05
	1.00

a. Assuming that Clyde's stocking decision is optimal, what is the implied range of excess cost per machine?

b. Your answer from part *a* has been presented to Clyde, who protests that the amount is too low. Does this suggest an increase or a decrease in the number of rug machines he stocks? Explain.

c. Suppose now that the $10 mentioned as profit is instead the excess cost per day for each machine and that the shortage cost is unknown. Assuming that the optimal number of machines is four, what is the implied range of shortage cost per machine?

41. A manager is going to purchase new processing equipment and must decide on the number of spare parts to order with the new equipment. The spares cost $200 each, and any unused spares will have an expected salvage value of $50 each. The probability of usage can be described by this distribution:

Number	0	1	2	3
Probability	.10	.50	.25	.15

If a part fails and a spare is not available, it will take two days to obtain a replacement and install it. The cost for idle equipment is $500 per day. What quantity of spares should be ordered?

42. A Las Vegas supermarket bakery must decide how many wedding cakes to prepare for the upcoming weekend. Cakes cost $33 each to make, and they sell for $60 each. Unsold cakes are reduced to half-price on Monday, and typically one-third of those are sold. Any that remain are donated to a nearby senior center. Analysis of recent demand resulted in the following table:

Demand	0	1	2	3
Probability	.15	.35	.30	.20

How many cakes should be prepared to maximize expected profit?

UPD Manufacturing

CASE

UPD Manufacturing produces a range of health-care appliances for hospital as well as for home use. The company has experienced a steady demand for its products, which are highly regarded in the health-care field. Recently the company has undertaken a review of its inventory ordering procedures as part of a larger effort to reduce costs.

One of the company's products is a blood pressure testing kit. UPD manufactures all of the components for the kit in-house except for the digital display unit. The display units are ordered at six-week intervals from the supplier. This ordering system began about five years ago, because the supplier insisted on it. However, that supplier was bought out by another supplier about a year ago, and the six-week ordering requirement is no longer in place. Nonetheless, UPD has continued to use the six-week ordering policy. According to purchasing manager Tom Chambers, "Unless somebody can give me a reason for changing, I'm going to stick with what we've been doing. I don't have time to reinvent the wheel."

Further discussions with Tom revealed a cost of $32 to order and receive a shipment of display units from the supplier. The company assembles 89 kits a week. Also, information from Sara James, in Accounting, indicated a weekly carrying cost of $.08 for each display unit.

The supplier has been quite reliable with deliveries; orders are received five working days after they are faxed to the supplier. Tom indicated that as far as he was concerned, lead-time variability is virtually nonexistent.

Questions

1. Would using an order interval other than every six weeks reduce costs? If so, what order interval would be best, and what order size would that involve?
2. Would you recommend changing to the optimal order interval? Explain.

Harvey Industries

CASE

Background

Harvey Industries, a Wisconsin company, specializes in the assembly of high-pressure washer systems and in the sale of repair parts for these systems. The products range from small portable high-pressure washers to large industrial installations for snow removal from vehicles stored outdoors during the winter months. Typical uses for high-pressure water cleaning include:

- Automobiles
- Airplanes
- Building maintenance
- Barns
- Engines
- Ice cream plants
- Lift trucks
- Machinery
- Swimming pools

Industrial customers include General Motors, Ford, Chrysler, Delta Airlines, United Parcel Service, and Shell Oil Company.

Although the industrial applications are a significant part of its sales, Harvey Industries is primarily an assembler of equipment for coin operated self-service car wash systems. The typical car wash is of concrete block construction with an equipment room in the center, flanked on either side by a number of bays. The cars are driven into the bays where the owner can wash and wax the car, utilizing high-pressure hot water and liquid wax. A dollar bill changer is available to provide change for the use of the equipment and the purchase of various products from dispensers. The products include towels, tire cleaner, and upholstery cleaner.

In recent years Harvey Industries has been in financial difficulty. The company has lost money for three of the last four years, with the last year's loss being $17,174 on sales of $1,238,674. Inventory levels have been steadily increasing to their present levels of $124,324.

The company employs 23 people with the management team consisting of the following key employees: president, sales manager, manufacturing manager, controller, and purchasing manager. The abbreviated organization chart reflects the reporting relationship of the key employees and the three individuals who report directly to the manufacturing manager.

Current Inventory Control System

The current inventory control "system" consists of orders for stock replenishment being made by the stockroom foreman, the purchasing manager, or the manufacturing manager whenever one of them notices that the inventory is low. An order for replenishment of inventory is also placed whenever someone (either a customer or an employee in the assembly area) wants an item and it is not in stock.

Some inventory is needed for the assembly of the high-pressure equipment for the car wash and industrial applications. There are current and accurate bills of material for these assemblies. The material needs to support the assembly schedule are generally known well in advance of the build schedule.

The majority of inventory transactions are for repair parts and for supplies used by the car washes, such as paper towels, detergent, and wax concentrate. Because of the constant and rugged use of the car wash equipment, there is a steady demand for the various repair parts.

The stockroom is well organized, with parts stored in locations according to each vendor. The number of vendors is relatively limited, with each vendor generally supplying many different parts. For example, the repair parts from Allen Bradley, a manufacturer of electrical motors, are stocked in the same location. These repair parts will be used to provide service for the

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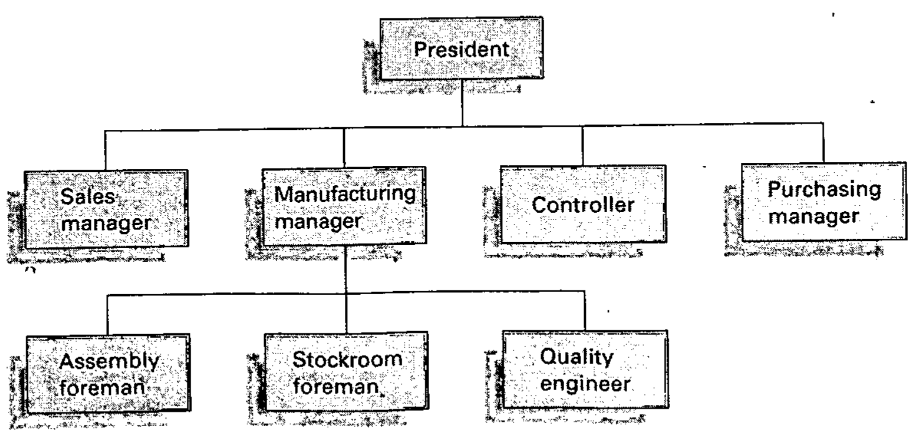

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many electrical motors that are part of the high-pressure pump and motor assembly used by all of the car washes.

Because of the heavy sales volume of repair parts, there are generally two employees working in the stockroom—a stockroom foreman who reports to the manufacturing manager and an assistant to the foreman. One of these two employees will handle customer orders. Many customers stop by and order the parts and supplies they need. Telephone orders are also received and are shipped by United Parcel Service the same day.

The assembly area has some inventory stored on the shop floor. This inventory consists of low-value items that are used every day, such as nuts, bolts, screws, and washers. These purchased items do not amount to very much dollar volume throughout the year. Unfortunately, oftentimes the assembly area is out of one of these basic items and this causes a significant amount of downtime for the assembly lines.

Paperwork is kept to a minimum. A sales slip listing the part numbers and quantities sold to a customer is generally made out for each sale. If the assembly department needs items that are not stocked on the assembly floor, someone from that department will enter the stockroom and withdraw the necessary material. There is no paperwork made out for the items needed on the assembly floor.

There were 973 different part numbers purchased for stock last year and those purchases amounted to $314,673. An analysis of inventory records shows that $220,684 was spent on just 179 of the part numbers.

Fortunately for Harvey Industries, most of the items they purchase are stocked by either the manufacturer or by a wholesaler. When it is discovered that the company is out of stock on an item, it generally takes only two or three days to replenish the stock.

Due to the company's recent losses, its auditing firm became concerned about the company's ability to continue in business. Recently the company sold off excess vacant land adjoining its manufacturing facility to generate cash to meet its financial obligations.

New President

Because of the recent death of the owner, the trust department of a Milwaukee Bank (as trustee for the state) has taken over the company's affairs and has appointed a new company president. The new president has identified many problem areas—one of which is improper inventory control. He has retained you as a consultant to make specific recommendations concerning a revised inventory control system. What are your recommendations and their rationale?

Source: Case "Harvey Industries" by Donald Condit presented at Midwest Case Writer's Association Workshop, 1984.

Grill Rite

CASE

Grill Rite is an old-line company that started out making wooden matches. As that business waned, the company entered the electric barbecue grill market, with five models of grills it sells nationally. For many years the company maintained a single warehouse from which it supplied its distributors.

The plant where the company produces barbecue sets is located in a small town, and many workers have been with the company for many years. During the transition from wooden matches to barbecue grills, many employees gave up their weekends to help with changing over the plant and learning the new skills they would need, without pay. In fact, Mac Wilson, the company president, can reel off a string of such instances of worker loyalty. He has vowed to never layoff any workers, and to maintain a full employment, steady rate of output. "Yes, I know demand for these babies (barbecue grills) is seasonal, but the inventory boys will just have to deal with it. On an annual basis, our output matches sales."

Inventory is handled by a system of four warehouses. There is a central warehouse located near the plant that supplies some customers directly, and the three regional warehouses.

The vice president for sales, Julie Berry, is becoming increasingly frustrated with the inventory system that she says "is antiquated and unresponsive." She points to increasing complaints from regional sales managers about poor customer service, saying customer orders go unfilled or are late, apparently due to shortages at the regional warehouse. Regional warehouse managers, stung by complaints from sales managers, have responded by increasing their order sizes from the main warehouse, and maintaining larger amounts of safety stock. This has resulted in increased inventory holding costs, but it hasn't eliminated the problem. Complaints are still coming in from sales people about shortages and lost sales. According to managers of the regional warehouses, their orders to the main warehouse aren't being shipped, or when they are, they are smaller quantities than requested. The manager of the main warehouse, Jimmy Joe ("JJ") Sorely, says his policy is to give preference to "filling direct orders from actual customers, rather than warehouse orders that might simply reflect warehouses trying to replenish their safety stock. And besides, I never know when I'll get hit with an order from one of the regional warehouses. I guess they think we've got an unlimited supply." Then he adds, "I thought when we added the warehouses, we could just divide our inventory among the warehouses, and everything would be okay."

When informed of the "actual customers" remark, a regional warehouse manager exclaimed, "We're their biggest customer!"

Julie Berry also mentioned that on more than one occasion she has found that items that were out of stock at one regional warehouse were in ample supply in at least one other regional warehouse.

Take the position of a consultant called in by president Mac Wilson. What recommendations can you make to alleviate the problems the company is encountering?

Bruegger's Bagel Bakery

OPERATIONS TOUR

www.brueggers.com

Bruegger's Bagel Bakery makes and sells a variety of bagels, including plain, onion, poppyseed, and cinnamon raisin, as well as assorted flavors of cream cheese. Bagels are the major source of revenue for the company.

The bagel business is a $3 billion industry. Bagels are very popular with consumers. Not only are they relatively low in fat, they are filling, and they taste good! Investors like the bagel industry because it can be highly profitable: it only costs about $.10 to make a bagel, and they can be sold for $.50 each or more. Although some bagel companies have done poorly in recent years, due mainly to poor management, Bruegger's business is booming; it is number one nationally, with over 450 shops that sell bagels, coffee, and bagel sandwiches for take-out or on-premise consumption. Many stores in the Bruegger's chain generate an average of $800,000 in sales annually.

Production of bagels is done in batches, according to flavor, with each flavor being produced on a daily basis. Production of bagels at Bruegger's begins at a processing plant, where the basic ingredients of flour, water, yeast, and flavorings are combined in a special mixing machine. After the dough has been thoroughly mixed, it is transferred to another machine that shapes the dough into individual bagels. Once the bagels have been formed, they are loaded onto refrigerated trucks for shipping to individual stores. When the bagels reach a store, they are unloaded from the trucks and temporarily stored while they rise. The final two steps of processing involve boiling the bagels in a kettle of water and malt for one minute, and then baking the bagels in an oven for approximately 15 minutes.

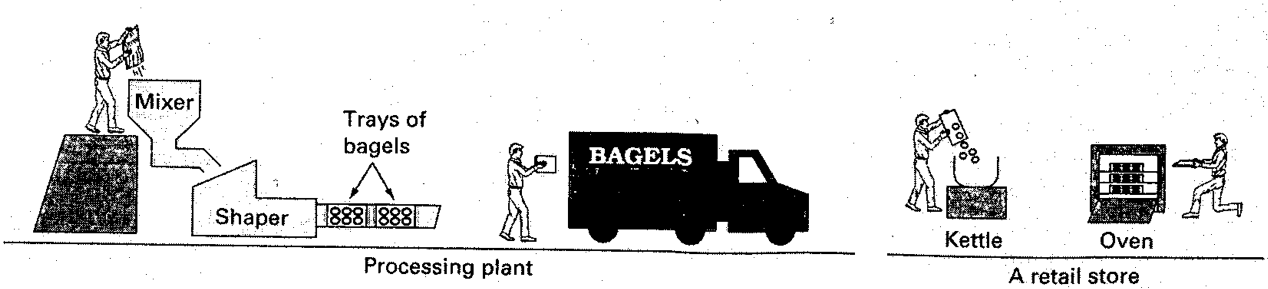
The process is depicted in the Figure.

Quality is an important feature of a successful business. Customers judge the quality of bagels by their appearance (size, shape, and shine), taste, and consistency. Customers are also sensitive to the service they receive when they make their purchases. Bruegger's devotes careful attention to quality at every stage of operation, from choosing suppliers of ingredients, careful monitoring of ingredients, and keeping equipment in good operating condition to monitoring output at each step in the process. At the stores, employees are instructed to watch for deformed bagels and to remove them when they find them. (Deformed bagels are returned to a processing plant where they are sliced into bagel chips, packaged, and then taken back to the stores for sale, thereby reducing the scrap rate.) Employees who work in the stores are carefully chosen and then trained so that they are competent to operate the necessary equipment in the stores and to provide the desired level of service to customers.

The company operates with minimal inventories of raw materials and inventories of partially completed bagels at the plant and very little inventory of bagels at the stores. One reason for this is to maintain a high degree of freshness in the final product by continually supplying fresh product to the stores. A second reason is to keep costs down; minimal inventories mean less space is needed for storage.

Questions

1. Bruegger's maintains relatively little inventory at either its plants or its retail stores. List the benefits and risks of this policy.
2. Quality is very important to Bruegger's.
   a. What features of bagels do customers look at to judge their quality?
   b. At what points in the production process do workers check bagel quality?
   c. List the steps in the production process, beginning with purchasing ingredients, and ending with the sale, and state how quality can be positively affected at each step.
3. Which inventory models could be used for ordering the ingredients for bagels? Which model do you think would be most appropriate for deciding how many bagels to make in a given batch?
4. Bruegger's has bagel-making machines at its plants. Another possibility would be to have a bagel-making machine at each store. What advantages does each alternative have?



PSC, Inc.

OPERATIONS TOUR

www.pscnet.com

PSC designs and produces a variety of laser bar code scanning devices. The products include hand-held bar code readers, high-speed fixed position industrial scanners, and retail check-out scanners as well as a full line of accessories, software, and supplies to support its products. Headquartered in Eugene, OR, the company has manufacturing facilities in Eugene, and Paris, France, with roughly 1,200 employees worldwide.

Products

Bar code scanners are designed for a variety of situations that can involve long range scanning, reading small bar codes, and performing high-speed scans. They are used extensively in industry, business, and government to manage and control the entire supply chain, which includes suppliers, production, warehousing, distribution, retail sales, and service. Examples of bar code readers include the familiar point-of-sale scanners encountered at supermarkets and other retail stores. They come in a variety of forms, ranging from hand-held to built-in models. High-speed, unattended scanners are used for automated material handling and sorting. Typical installations include high-volume distribution centers such as JC Penney's catalog operation and airport baggage handling systems. The company also produces "reader engines" that it supplies to other companies for use in their products. These may be as small as 1.2 cubic inches. One application for an "engine product" is found in lottery ticket validation machines. Use of bar code readers has greatly increased the speed and accuracy of data collection, resulting in increased productivity, improved production and inventory tracking and control, and improved market information.

Operations

Forecasting Forecasting is not a significant activity at PSC due to several factors. There is high standardization of scanner components, which creates stability in usage requirements. Supplier lead times are relatively short, often only a few days. Orders are typically small; 70 percent of all orders are for 10 units or less. There is a fair degree of production flexibility, particularly in terms of product customization. As a result of these factors, the company relies mainly on short-term, moving average forecasts.

Product Design PSC has developed a robust design in many of its products, enabling them to perform effectively under a broad range of operating conditions. For example, many of its hand-held scanners can operate at temperatures ranging from −22° F to 120° F, and can withstand drops onto concrete surfaces from heights up to six feet and still function. This has enabled the company to offer warranties ranging from 24 to 36 months, far exceeding the industry standard of 3 to 12 months.

Layout PSC has developed an efficient production layout that consists of assembly lines and work centers. The assembly lines handle standardized production and subassemblies and the work centers handle final assembly and customization of products. Assembly lines are U-shaped to facilitate communication among workers. The work centers are designed for production flexibility; they can be reconfigured in about four hours. Work centers are staffed by teams of three to six cross-trained workers who are responsible for an order from start to finish.

The Production Process Production involves a combination of assembly line and batch processing that provides high volume and flexibility to customized individual orders. Because of the high standardization among the internal components of different scanners, many of the subassemblies can be produced on assembly lines. Customization is done primarily on the external portion of various products according to customer specification.

The production process for scanner engines is depicted in the process flowchart shown in the figure. The process begins when an order is received from a customer. The order is then configured according to customer specifications. Next it is entered into the computer to obtain a bill of materials (BOM), and the order is transmitted to production control so that it can be scheduled for production. A "traveler" packet containing product specifications and the BOM is created. It will accompany the order throughout the process.

The traveler is sent to the "kitting" area where standard parts and any customized parts are obtained and placed into a bin ("kit") and then placed in a flow rack until the assigned work center is ready for the job (i.e., a pull system).

The next phase of the process transforms unprogrammed, panelized circuit boards into programmed boards. The boards first pass through a screen printer which uses a stencil to coat the boards with a solder paste. Next the boards pass through a chip mounter which enters values for the smaller, passive components of the circuit board at a rate of 25,000 parts per hour. A second mounter enters values for the larger, programmable components at a rate of 7,000 parts per hour. The slower rate for the larger components is offset by the fact that there are fewer of those components. The process ends up being balanced, and no bottlenecks occur.

The programmed boards move by conveyor to a station for visual inspection. Rejects are returned to the chip mounter area, and boards that pass are sent through an oven to solidify the solder, making the programming permanent. The circuit boards are then removed from the panels and placed into the

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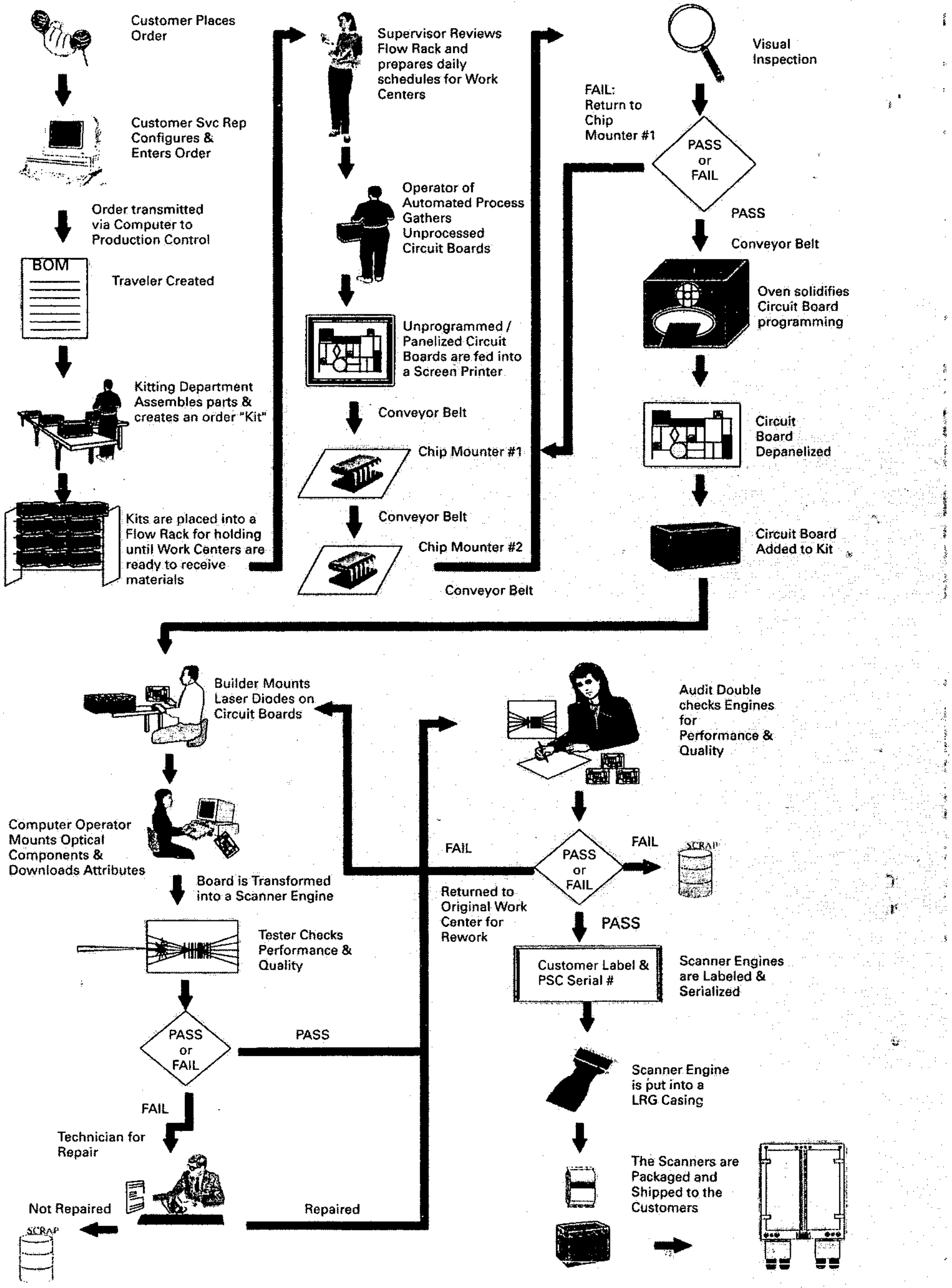
PSC Inc. Scanner Engine Production Process Flow Chart



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kit. The kits are then taken to designated work centers for customization and placement in scanner engines.

Work centers typically have builders, computer operators, and a tester. A builder mounts the laser diodes on the circuit board and passes it to a computer operator who downloads the customer specifications into the microprocessor of the scan engine. The operator also mounts the optical components and adjusts them for the design of the scanner (e.g., long range scanning). Next, the engine goes to the tester, who checks to make sure that the scanner is capable of reading bar codes and laser characteristics. Engines that fail are sent for repair and later retested. If the engine fails a second time, it is either returned for further repair or scrapped. Engines which pass are placed in an electrostatic bag which protects them from static electricity that could damage the programming.

Engines are then sent to Audit for another check for performance quality.

Engines that pass are incorporated into the final product, a serial number is added, along with a label, and the product is sent to the packing area and then shipped to the customer.

Inventory The company uses a variety of methods for inventory management, and it attempts to minimize the amount of inventory. A computer determines component requirements and generates purchase orders for the components for each order, and then appropriate orders for various components from vendors are prepared. However, the company maintains a stock of standard components that are replenished using a reorderpoint system. The company has adopted point-of-use replenishment for some areas of operations, having deliveries come directly to the production floor. Finished products are immediately shipped to the customer, which enhances the company's delivery performance and avoids finished goods inventory.

Suppliers Approximately 40 vendors supply parts and materials to PSC, each of which has been subjected to a multiple-step supplier certification program that includes the supplier completing a self-evaluation questionnaire; an on-site visit of supplier facilities by a team from PSC made up of people from engineering, purchasing, and operations; a probation period; and rating of products using government MIL-STD 105 specifications. Vendor performance is tracked on product quality, delivery, and service.

When an item is removed from inventory, it is scanned into the computer, and this information is transmitted directly to suppliers, along with purchase orders to restock components.

Quality Quality is strongly emphasized at PSC. Employees are trained in quality concepts and the use of quality tools. Training is incorporated on-the-job so that employees can see the practical applications of what they are learning. Employees are responsible for performing in-process quality checks (quality at the source), and to report any defects they discover to their supervisor. Defects are assigned to one of three categories for problem solving:

- Operator/training error. The supervisor notifies a trainer who then provides appropriate retraining.
- Process/equipment problem. The supervisor notifies the manufacturing engineer who is then responsible for diagnosing the cause and correcting the problem.
- Parts/material problem. The supervisor notifies quality assurance, who then notifies the vendor to correct the problem. Defective parts are either scrapped or returned to the vendor.

Lean Production

PSC strives to operate on lean production principles. In addition to emphasizing high levels of quality, production flexibility, low levels of inventories, and having some deliveries come right to the production floor, its organization structure is fairly flat, and it uses a team approach. Still another feature of lean production is that many of PSC's workers are multi-skilled. The company encourages employees to master new skills through a pay-for-skill program, and bases hourly pay rates on the number of skills a worker can perform.

Business Strategy

The company has developed what it believes is a strong strategy for success. Strategic initiatives include anticipating customer demand for miniaturization and the ability to customize products; expanding its proprietary technology; and expanding internationally into Western Europe (now accounts for about 35 percent of sales) and the Pacific rim (now accounts for about 10 percent of sales). Several plants or groups are ISO certified, which has been important for European sales. The company intends to continue to expand its product lines through acquisition of other companies.

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CHAPTER 12

Aggregate Planning

LEARNING OBJECTIVES

After completing this chapter, you should be able to:

1. Explain what aggregate planning is and how it is useful.
2. Identify the variables decision makers have to work with in aggregate planning and some of the possible strategies they can use.
3. Describe some of the graphical and quantitative techniques planners use.
4. Prepare aggregate plans and compute their costs.

CHAPTER OUTLINE

Seasonal variations in demand are quite common in many industries and public services, such as air-conditioning, fuel, public utilities, police and fire protection, and travel. And these are just a few examples of industries and public services that have to deal with uneven demands. Generally speaking, organizations cannot predict exactly the quantity and timing of demands for specific products or services months in advance under these conditions. Even so, they typically must assess their capacity needs (e.g., labor, inventories) and costs months in advance in order to be able to handle demand. How do they do it? They use a process often referred to as *aggregate planning.* That is the subject of this chapter.

In the spectrum of production planning, **aggregate planning** is intermediate-range capacity planning that typically covers a time horizon of 2 to 12 months, although in some companies it may extend to as much as 18 months. It is particularly useful for organizations that experience seasonal or other fluctuations in demand or capacity. The goal of aggregate planning is to achieve a production plan that will effectively utilize the organization's resources to satisfy expected demand. Planners must make decisions on output rates, employment levels and changes, inventory levels and changes, back orders, and subcontracting in or out.

aggregate planning Intermediate-range capacity planning, usually covering 2 to 12 months.

INTRODUCTION

Intermediate Planning in Perspective

Organizations make capacity decisions on three levels: long term, intermediate term, and short term. Long-term decisions relate to product and service selection (i.e., determining which products or services to offer), facility size and location, equipment decisions, and layout of facilities. These long-term decisions essentially establish the capacity constraints within which

TABLE 12.1
Overview of planning levels (chapter numbers are shown)

Long-range plans	Intermediate plans	Short-range plans
Long-term capacity} 5	General levels of:	Detailed plans:
Location } 8	Employment	Machine loading } 15
Layout } 6	Output	Job assignments } 15
Product design } 4	Finished-goods inventories	Job sequencing } 15
Work system design } 7	Subcontracting	Production lot size } 11
	Backorders	Order quantities } 11
		Work schedules } 15

intermediate planning must function. Intermediate decisions, as noted above, relate to general levels of employment, output, and inventories, which in turn establish boundaries within which short-range capacity decisions must be made. Thus, short-term decisions essentially consist of deciding the best way to achieve desired results within the constraints resulting from long-term and intermediate-term decisions. Short-term decisions involve scheduling jobs, workers and equipment, and the like. The three levels of capacity decisions are depicted in Table 12.1. Long-term capacity decisions were covered in Chapter 5, and scheduling and related matters are covered in Chapter 15. This chapter covers intermediate capacity decisions.

Many business organizations develop a *business plan* that encompasses both long-term and intermediate-term planning. The business plan establishes guidelines for the organization, taking into account the organization's strategies and policies; forecasts of demand for the organization's products or services; and economic, competitive, and political conditions. A key objective in business planning is to coordinate the intermediate plans of various organization functions, such as marketing, operations, and finance. In manufacturing companies, coordination also includes engineering and materials management. Consequently, all of these functional areas must work together to formulate the aggregate plan. Aggregate planning decisions are strategic decisions that define the framework within which operating decisions will be made. They are the starting point for scheduling and production control systems. They provide input for financial plans; they involve forecasting input and demand management, and they may require changes in employment levels. And if the organization is involved in *time-based competition,* it will be important to incorporate some flexibility in the aggregate plan to be able to handle changing requirements promptly. As noted, the plans must fit into the framework established by the organization's long-term goals and strategies, and the limitations established by long-term facility and capital budget decisions. The aggregate plan will guide the more detailed planning that eventually leads to a *master schedule.* Figure 12.1 illustrates the planning sequence.

Aggregate planning also can serve as an important input to other strategic decisions; for example, management may decide to add capacity when aggregate planning alternatives for temporarily increasing capacity, such as working overtime and subcontracting, are too costly.

The Concept of Aggregation

Aggregate planning is essentially a "big picture" approach to planning. Planners usually try to avoid focusing on individual products or services—unless the organization has only one major product or service. Instead, they focus on a group of similar products or services, or sometimes an entire product or service line. For example, planners in a company producing television sets would not concern themselves with 21-inch sets versus 25-inch or 27-inch sets. Instead, planners would lump all models together and deal with them as though they were a single product; hence, the term *aggregate* planning. Thus, when fast-food companies such as McDonald's, Burger King, or Wendy's plan employment and output levels, they don't try to determine how demand will be broken down into the various menu options they offer; they focus on overall demand and the overall capacity they want to provide.

Now, consider how aggregate planning might work in a large department store. Space allocation is often an aggregate decision. That is, a manager might decide to allocate 20 percent of the available space in the clothing department to women's sportswear, 30 percent to juniors,

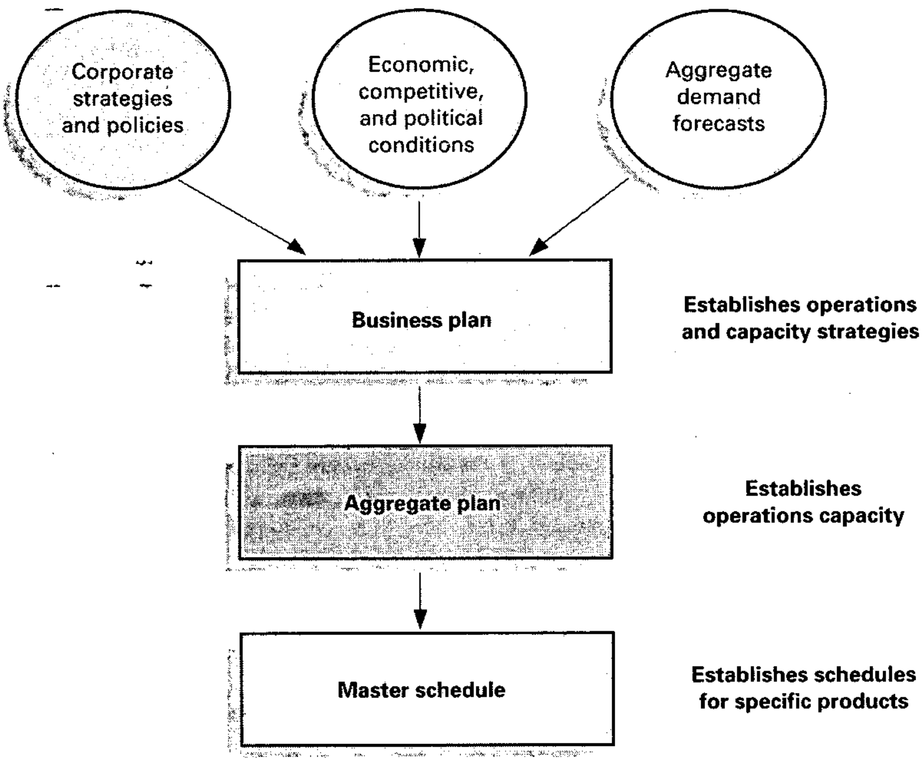

FIGURE 12.1

Planning sequence

Rubbermaid Incorporated, a multinational manufacturer of commercial and household food containers and other items, produces more than 4,000 products sold in 100 countries. At its corporate headquarters in Wooster, Ohio, a planning team discusses product sales performance.

www.rubbermaid.com

and so on, without regard for what brand names will be offered or how much of juniors will be jeans. The aggregate measure might be square feet of space or racks of clothing.

For purposes of aggregate planning, it is often convenient to think of capacity in terms of labor hours or machine hours per period, or output rates (barrels per period, units per period), without worrying about how much of a particular item will actually be involved. This approach frees planners to make general decisions about the use of resources without having to get into the complexities of individual product or service requirements. Product groupings make the problem of obtaining an acceptable unit of aggregation easier because product groupings may lend themselves to the same aggregate measures.

Why do organizations need to do aggregate planning? The answer is twofold. One part is related to *planning:* It takes time to implement plans. For instance, if plans call for hiring (and training) new workers, that will take time. The second part is strategic: *Aggregation* is important because it is not possible to predict with any degree of accuracy the timing and volume of demand for individual items. So if an organization were to "lock in" on individual items, it would lose the flexibility to respond to the market.

Generally speaking, aggregate planning is connected to the budgeting process. Most organizations plan their financial requirements annually on a department-by-department basis.

Finally, aggregate planning is important because it can help synchronize flow throughout the supply chain; it affects costs, equipment utilization, employment levels, and customer satisfaction.

An Overview of Aggregate Planning

Aggregate planning begins with a forecast of aggregate demand for the intermediate range. This is followed by a general plan to meet demand requirements by setting output, employment, and finished-goods inventory levels or service capacities. Managers might consider a number of plans, each of which must be examined in light of feasibility and cost. If a plan is reasonably good but has minor difficulties, it may be reworked. Conversely, a poor plan should be discarded and alternative plans considered until an acceptable one is uncovered. The production plan is essentially the output of aggregate planning.

Aggregate plans are updated periodically, often monthly, to take into account updated forecasts and other changes. This results in a *rolling planning horizon* (i.e., the aggregate plan always covers the next 12–18 months).

Demand and Capacity Aggregate planners are concerned with the *quantity* and the *timing* of expected demand. If total expected demand for the planning period is much different from available capacity over that same period, the major approach of planners will be to try to achieve a balance by altering capacity, demand, or both. On the other hand, even if capacity and demand are approximately equal for the planning horizon as a whole, planners may still be faced with the problem of dealing with uneven demand *within* the planning interval. In some periods, expected demand may exceed projected capacity, in others expected demand may be less than projected capacity, and in some periods the two may be equal. The task of aggregate planners is to achieve rough equality of demand and capacity over the entire planning horizon. Moreover, planners are usually concerned with minimizing the cost of the aggregate plan, although cost is not the only consideration.

Inputs to Aggregate Planning Effective aggregate planning requires good *information*. First, the available resources over the planning period must be known. Then, a forecast of expected demand must be available. Finally, planners must take into account any policies regarding changes in employment levels (e.g., some organizations view layoffs as extremely undesirable, so they would use that only as a last resort).

Table 12.2 lists the major inputs to aggregate planning.

Companies in the travel industry and some other industries often experience duplicate orders from customers who make multiple reservations but only intend to keep at most one of them. This makes capacity planning all the more difficult.

Duplicate Orders Can Lead to Excess Capacity READING

We've all heard about someone who booked seats on two airlines, or reserved two hotel rooms, usually because travel plans weren't firmed up, but they didn't want to miss out on their trip. Later, they cancel one set of reservations. This sort of duplicate ordering isn't just limited to the travel industry. The trouble is, companies base their capacity planning on demand estimates, and when there are numerous duplicate orders, it is easy to overestimate demand and end up with excess capacity. In some instances, this has led companies to expand at a time when demand was actually leveling off or even decreasing! The problem is further compounded if companies conclude that

(continued)

(concluded)
canceled orders reflect customers' reluctance to wait, and respond by *adding* capacity when, in fact, order cancellation may actually reflect duplicate ordering.

Some semiconductor companies downplay data on bookings because it is too difficult to distinguish between duplicate orders and actual demand.

Yet it is important to account for double orders. Otherwise, by counting duplicate orders as true demand, you overestimate the demand rate, and by counting the cancellations of duplicate orders as lost sales, you overestimate customers' sensitivity to delay, and then you wind up with excess capacity.

"The optimal level of capacity increases with customers' sensitivity to delay, so estimating customers' sensitivity to delay is a very important part of the puzzle."

Duplicate orders can make capacity planning very difficult. The key is to carefully estimate both the rate of duplicate ordering and the degree of order cancellation that can be attributed to duplicate ordering.

Source: Based on Mor Armony and Erica L. Plambeck, "The Impact of Duplicate Orders on Demand Estimation and Capacity Investment," GSB Research Paper #1740, Graduate School of Business, Stanford University, June 2002.

Demand and Capacity Options

Aggregate planning strategies can be described as proactive, reactive, or mixed. *Proactive* strategies involve demand options: They attempt to alter demand so that it matches capacity. *Reactive* strategies involve capacity options: They attempt to alter capacity so that it matches demand. *Mixed* strategies involve an element of each of these approaches.

Demand Options The basic demand options are the following:

1. *Pricing.* Pricing differentials are commonly used to shift demand from peak periods to off-peak periods. Some hotels, for example, offer lower rates for weekend stays, and some airlines offer lower fares for night travel. Movie theaters may offer reduced rates for matinees, and some restaurants offer "early bird specials" in an attempt to shift some of the heavier dinner demand to an earlier time that traditionally has less traffic. Some restaurants also offer smaller portions at reduced rates, and most have smaller portions and prices for children. To the extent that pricing is effective, demand will be shifted so that it corresponds more closely to capacity, albeit for an *opportunity cost* that represents the lost profit stemming from capacity insufficient to meet demand during certain periods.

An important factor to consider is the *degree* of price elasticity for the product or service; the more the elasticity, the more effective pricing will be in influencing demand patterns.

TABLE 12.2
Aggregate planning inputs and outputs

Inputs	Outputs
Resources	Total cost of a plan
Workforce/production rates	Projected levels of
Facilities and equipment	Inventory
Demand forecast	Output
Policies on workforce changes	Employment
Subcontracting	Subcontracting
Overtime	Backordering
Inventory levels/changes	
Back orders	
Costs	
Inventory carrying cost	
Back orders	
Hiring/firing	
Overtime	
Inventory changes	
Subcontracting	

2. *Promotion.* Advertising and other forms of promotion, such as displays and direct marketing, can sometimes be very effective in shifting demand so that it conforms more closely to capacity. Obviously, timing of these efforts and knowledge of response rates and response patterns will be needed to achieve the desired results. Unlike pricing policy, there is much less control over the timing of demand, so there is the risk that promotion can worsen the condition it was intended to improve, by bringing in demand at the wrong time, further stressing capacity.

3. *Back orders.* An organization can shift demand to other periods by allowing back orders. That is, orders are taken in one period and deliveries promised for a later period. The success of this approach depends on how willing customers are to wait for delivery. Moreover, the costs associated with back orders can be difficult to pin down since it would include lost sales, annoyed or disappointed customers, and perhaps additional paperwork.

4. *New demand.* Many organizations are faced with the problem of having to provide products or services for peak demand in situations where demand is very uneven. For instance, demand for bus transportation tends to be more intense during the morning and late afternoon rush hours but much lighter at other times. Creating new demand for buses at other times (e.g., trips by schools, clubs, and senior citizen groups) would make use of the excess capacity during those slack times. Similarly, many fast-food restaurants are open for breakfast to use their capacities more fully, and some landscaping firms in northern climates use their equipment during the winter months for snow removal. Manufacturing firms that experience seasonal demands for certain products (e.g., snowblowers) are sometimes able to develop a demand for a complementary product (e.g., lawn mowers, garden equipment) that makes use of the same production processes. They thereby achieve a more consistent use of labor, equipment, and facilities. Another option may be "insourcing" work from another organization.

Capacity Options The basic capacity options are the following:

1. *Hire and lay off workers.* The extent to which operations are labor intensive determines the impact that changes in the workforce level will have on capacity. The resource requirements of each worker also can be a factor. For instance, if a supermarket usually has 10 of 14 checkout lines operating, an additional four checkout workers could be added. Hence, the ability to add workers is constrained at some point by other resources needed to support the workers. Conversely, there may be a lower limit on the number of workers needed to maintain a viable operation (e.g., a skeleton crew).

Union contracts may restrict the amount of hiring and laying off a company can do. Moreover, because laying off can present serious problems for workers, some firms have policies that either prohibit or limit downward adjustments to a workforce. On the other hand, hiring presumes an available supply of workers. This may change from time to time and, at times of low supply, have an impact on the ability of an organization to pursue this approach.

Another consideration is the skill level of workers. Highly skilled workers are generally more difficult to find than lower-skilled workers, and recruiting them involves greater costs. So the usefulness of this option may be limited by the need for highly skilled workers.

Use of hiring and laying off entails certain costs. Hiring costs include recruitment, screening, and training to bring new workers "up to speed." And quality may suffer. Some savings may occur if workers who have recently been laid off are rehired. Layoff costs include severance pay, the cost of realigning the remaining workforce, potential bad feelings toward the firm on the part of workers who have been laid off, and some loss of morale for workers who are retained (i.e., in spite of company assurances, some workers will believe that in time they too will be laid off).

An increasing number of organizations view workers as assets rather than as variable costs, and would not consider this approach. Instead, they might use slack time for other purposes.

2. *Overtime/slack time.* Use of overtime or slack time is a less severe method for changing capacity than hiring and laying off workers, and it can be used across the board or selectively as needed. It also can be implemented more quickly than hiring and laying off and allows the firm to maintain a steady base of employees. The use of overtime can be especially attractive in dealing with seasonal demand peaks by reducing the need to hire and train people who will have to be laid off during the off-season. Overtime also permits the company to maintain a skilled workforce and employees to increase earnings, and companies may save money because fringe

and other benefits are generally fixed. Moreover, in situations with crews, it is often necessary to use a full crew rather than to hire one or two additional people. Thus, having the entire crew work overtime would be preferable to hiring extra people.

It should be noted that some union contracts allow workers to refuse overtime. In those cases, it may be difficult to muster a full crew to work overtime or to get an entire production line into operation after regular hours. Although workers often like the additional income overtime can generate, they may not appreciate having to work on short notice or the fluctuations in income that result. Still other considerations relate to the fact that overtime often results in lower productivity, poorer quality, more accidents, and increased payroll costs, whereas idle time results in less efficient use of machines and other fixed assets.

The use of slack when demand is less than capacity can be an important consideration. Some organizations use this time for training. It also can give workers time for problem solving and process improvement, while retraining skilled workers.

3. *Part-time workers.* In certain instances, the use of part-time workers is a viable option—much depends on the nature of the work, training and skills needed, and union agreements. Seasonal work requiring low-to-moderate job skills lends itself to part-time workers, who generally cost less than regular workers in hourly wages and fringe benefits. However, unions may regard such workers unfavorably because they typically do not pay union dues and may lessen the power of unions. Department stores, restaurants, and supermarkets make use of part-time workers. So do parks and recreation departments, resorts, travel agencies, hotels, and other service organizations with seasonal demands. In order to be successful, these organizations must be able to hire part-time employees when they are needed.

Some companies use contract workers, also called *independent contractors,* to fill certain needs. Although they are not regular employees, often they work alongside regular workers. In addition to having different pay scales and no benefits, they can be added or subtracted from the workforce with greater ease than regular workers, giving companies great flexibility in adjusting the size of the workforce.

4. *Inventories.* The use of finished-goods inventories allows firms to produce goods in one period and sell or ship them in another period, although this involves holding or carrying those goods as inventory until they are needed. The cost includes not only storage costs and the cost of money tied up that could be invested elsewhere, but also the cost of insurance, obsolescence, deterioration, spoilage, breakage, and so on. In essence, inventories can be built up during periods when production capacity exceeds demand and drawn down in periods when demand exceeds production capacity.

This method is more amenable to manufacturing than to service industries since manufactured goods can be stored whereas services generally cannot. However, an analogous approach used by services is to make efforts to streamline services (e.g., standard forms) or otherwise do a portion of the service during slack periods (e.g., organize the workplace). In spite of these possibilities, services tend not to make much use of inventories to alter capacity requirements. S

5. *Subcontracting.* Subcontracting enables planners to acquire temporary capacity, although it affords less control over the output and may lead to higher costs and quality problems. The question of whether to make or buy (i.e., in manufacturing) or to perform a service or hire someone else to do the work generally depends on factors such as available capacity, relative expertise, quality considerations, cost, and the amount and stability of demand.

Conversely, in periods of excess capacity, an organization may subcontract *in,* that is, conduct work for another organization. As an alternative to subcontracting, an organization might consider *outsourcing:* contracting with another organization to supply some portion of the goods or services on a regular basis.

BASIC STRATEGIES FOR MEETING UNEVEN DEMAND

As you see, managers have a wide range of decision options they can consider for achieving a balance of demand and capacity in aggregate planning. Since the options that are most suited to influencing demand fall more in the realm of marketing than in operations (with the exception of backlogging), we shall concentrate on the capacity options, which are in the realm of operations but include the use of back orders.

Aggregate planners might adopt a number of strategies. Some of the more prominent ones are

1. Maintain a level workforce.
2. Maintain a steady output rate.
3. Match demand period by period.
4. Use a combination of decision variables.

level capacity strategy Maintaining a steady rate of regular-time output while meeting variations in demand by a combination of options.

chase demand strategy Matching capacity to demand; the planned output for a period is set at the expected demand for that period.

While other strategies might be considered, these will suffice to give you a sense of how aggregate planning operates in a vast number of organizations. The first three strategies are "pure" strategies because each has a single focal point; the last strategy is "mixed" because it lacks the single focus. Under a **level capacity strategy,** variations in demand are met by using some combination of inventories, overtime, part-time workers, subcontracting, and back orders while maintaining a steady rate of output. Matching capacity to demand implies a **chase demand strategy;** the planned output for any period would be equal to expected demand for that period.

Many organizations regard a level workforce as very appealing. Since workforce changes through hiring and laying off can have a major impact on the lives and morale of employees and can be disruptive for managers, organizations often prefer to handle uneven demand in other ways. Moreover, changes in workforce size can be very costly, and there is always the risk that there will not be a sufficient pool of workers with the appropriate skills when needed. Aside from these considerations, such changes can involve a significant amount of paperwork. Unions tend to favor a level workforce because the freedom to hire and lay off workers diminishes union strengths.

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To maintain a constant level of output and still satisfy varying demand, an organization must resort to some combination of subcontracting, backlogging, and use of inventories to absorb fluctuations. Subcontracting requires an investment in evaluating sources of supply as well as possible increased costs, less control over output, and perhaps quality considerations. Backlogs can lead to lost sales, increased record keeping, and lower levels of customer service. Allowing inventories to absorb fluctuations can entail substantial costs by having money tied up in inventories, having to maintain relatively large storage facilities, and incurring other costs related to inventories. Furthermore, inventories are not usually an alternative for service-oriented organizations. However, there are certain advantages, such as minimum costs of recruitment and training, minimum overtime and idle-time costs, fewer morale problems, and stable use of equipment and facilities.

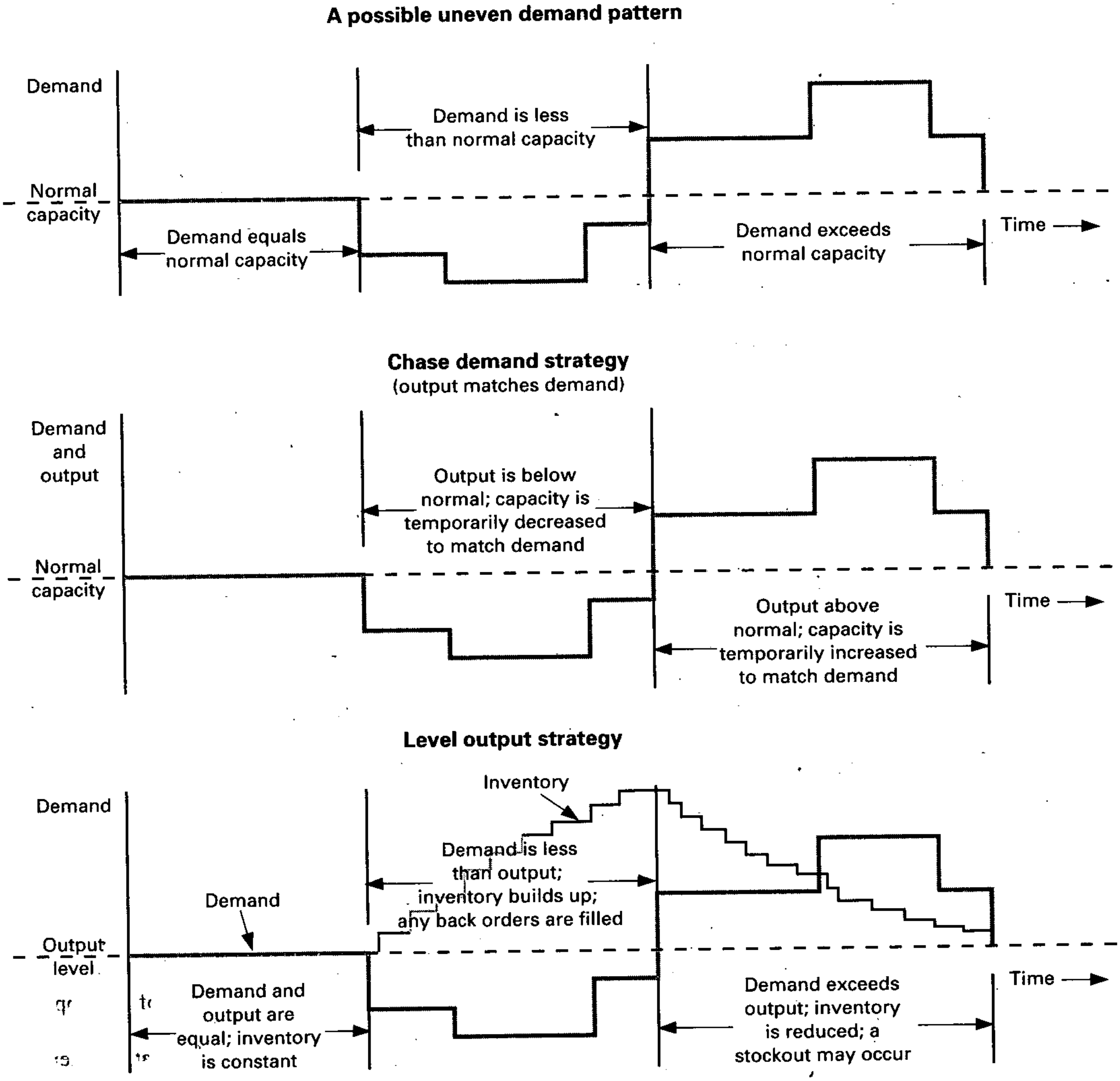
A chase demand strategy presupposes a great deal of ability and willingness on the part of managers to be flexible in adjusting to demand. A major advantage of this approach is that inventories can be kept relatively low, which can yield substantial savings for an organization. A major disadvantage is the lack of stability in operations—the atmosphere is one of dancing to demand's tune. Also, when forecast and reality differ, morale can suffer, since it quickly becomes obvious to workers and managers that efforts have been wasted. Figure 12.2 provides a comparison of the two strategies, using a varying demand pattern to highlight the differences in the two approaches. The same demand pattern is used for each approach. In the upper portion of the figure the pattern is shown. Notice that there are three situations: (1) demand and capacity are equal; (2) demand is less than capacity; and (3) demand exceeds capacity.

The middle portion of the figure illustrates what happens with a chase approach. When normal capacity would exceed demand, capacity is cut back to match demand. Then, when demand exceeds normal capacity, the chase approach is to temporarily increase capacity to match demand.

The bottom portion of the figure illustrates the level-output strategy. When demand is less than capacity, output continues at normal capacity, and the excess output is put into inventory

FIGURE 12.2

Comparison of chase and level strategies



in anticipation of the time when demand exceeds capacity. When demand exceeds capacity, inventory is used to offset the shortfall in output.

Organizations may opt for a strategy that involves some combination of the pure strategies. This allows managers greater flexibility in dealing with uneven demand and perhaps in experimenting with a wide variety of approaches. However, the absence of a clear focus may lead to an erratic approach and confusion on the part of employees.

Choosing a Strategy

Whatever strategy an organization is considering, two important factors are *company policy* and *costs*. Company policy may set constraints on the available options or the extent to which they can be used. For instance, company policy may discourage layoffs except under extreme conditions. Subcontracting may not be a viable alternative due to the desire to maintain secrecy about some aspect of the manufacturing of the product (e.g., a secret formula or blending process). Union agreements often impose restrictions. For example, a union contract may specify both minimum and maximum numbers of hours part-time workers can be used.

As a rule, aggregate planners seek to match supply and demand within the constraints imposed on them by policies or agreements and at minimum cost. They usually evaluate alternatives in terms of their overall costs. Table 12.3 compares reactive strategies. In the next section, a number of techniques for aggregate planning are described and presented with some examples of cost evaluation of alternative plans.

TABLE 12.3
Comparison of reactive strategies

Chase approach
Capacities (workforce levels, output rates, etc.) are adjusted to match demand requirements over the planning horizon.
Advantages:
- Investment in inventory is low
- Labor utilization is kept high

Disadvantage:
- The cost of adjusting output rates and/or workforce levels

Level approach
Capacities (workforce levels, output rates, etc.) are kept constant over the planning horizon.
Advantage:
- Stable output rates and workforce levels

Disadvantages:
- Greater inventory costs
- Increased overtime and idle time
- Resource utilizations that vary over time

TECHNIQUES FOR AGGREGATE PLANNING

Numerous techniques are available to help with the task of aggregate planning. Generally, they fall into one of two categories: informal trial-and-error techniques and mathematical techniques. In practice, informal techniques are more frequently used. However, a considerable amount of research has been devoted to mathematical techniques, and even though they are not as widely used, they often serve as a basis for comparing the effectiveness of alternative techniques for aggregate planning. Thus, it will be instructive to briefly examine them as well as the informal techniques.

A general procedure for aggregate planning consists of the following steps:

1. Determine demand for each period.
2. Determine capacities (regular time, overtime, subcontracting) for each period.
3. Identify company or departmental policies that are pertinent (e.g., maintain a safety stock of 5 percent of demand, maintain a reasonably stable workforce).
4. Determine unit costs for regular time, overtime, subcontracting, holding inventories, back orders, layoffs, and other relevant costs.
5. Develop alternative plans and compute the cost for each.
6. If satisfactory plans emerge, select the one that best satisfies objectives. Otherwise, return to step 5.

It can be helpful to use a worksheet or spreadsheet that summarizes demand, capacity, and cost for each plan, such as the one illustrated in Table 12.4. In addition, graphs can be used to guide development of alternatives.

TABLE 12.4
Worksheet/spreadsheet

Period	1	2	3	4	5		Total
Forecast							
Output							
Regular time							
Overtime							
Subcontract							
Output – Forecast							
Inventory							
Beginning							
Ending							
Average							
Backlog							
Costs							
Output							
Regular							
Overtime							
Subcontract							
Hire/Lay off							
Inventory							
Back orders							
Total							

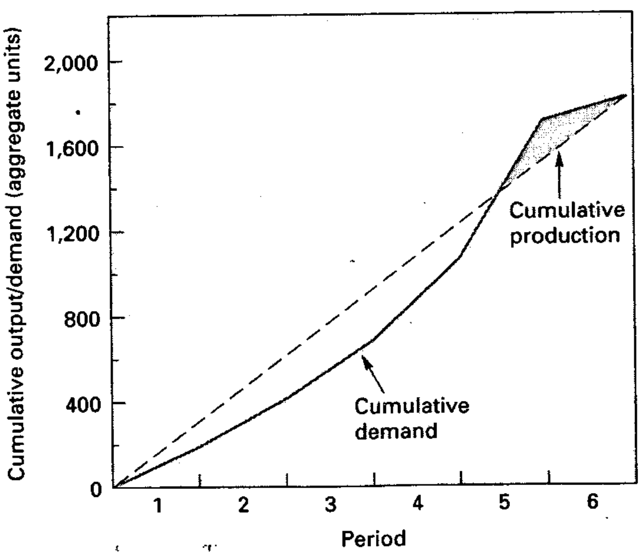


FIGURE 12.3
A cumulative graph

Trial-and-Error Techniques Using Graphs and Spreadsheets

Trial-and-error approaches consist of developing simple tables or graphs that enable planners to visually compare projected demand requirements with existing capacity. Alternatives are usually evaluated in terms of their overall costs. The chief disadvantage of such techniques is that they do not necessarily result in the optimal aggregate plan.

Very often, graphs can be used to guide the development of alternatives. Some planners prefer cumulative graphs while others prefer to see a period-by-period breakdown of a plan. For instance, Figure 12.3 shows a cumulative graph for a plan with steady output (the slope of the dashed line represents the production rate) and inventory absorption of demand variations. Figure 12.2 is an example of a period-by-period graph. The obvious advantage of a graph is that it provides a visual portrayal of a plan. The preference of the planner determines which of these two types of graphs is chosen.

Two examples illustrate the development and comparison of aggregate plans. In the first example, regular output is held steady, with inventory absorbing demand variations. In the second example, a lower rate of regular output is used, supplemented by use of overtime. In both examples, some backlogs are allowed to build up.

These examples and other examples and problems in this chapter are based on the following assumptions:

1. The regular output capacity is the same in all periods. No allowance is made for holidays, different numbers of workdays in different months, and so on. This assumption simplifies computations.
2. Cost (back order, inventory, subcontracting, etc.) is a linear function composed of unit cost and number of units. This often has a reasonable approximation to reality, although there may be only narrow ranges over which this is true. Cost is sometimes more of a step function.
3. Plans are feasible; that is, sufficient inventory capacity exists to accommodate a plan, subcontractors with appropriate quality and capacity are standing by, and changes in output can be made as needed.
4. All costs associated with a decision option can be represented by a lump sum or by unit costs that are independent of the quantity involved. Again, a step function may be more realistic; but for purposes of illustration and simplicity, this assumption is appropriate.
5. Cost figures can be reasonably estimated and are constant for the planning horizon.
6. Inventories are built up and drawn down at a uniform rate and output occurs at a uniform rate throughout each period. However, backlogs are treated as if they exist for an entire period, even though in periods where they initially appear, they would tend to build up toward the end of the period. Hence, this assumption is a bit unrealistic for some periods, but it simplifies computations.

In the examples and problems in this chapter, we use the following relationships to determine the number of workers, the amount of inventory, and the cost of a particular plan.

The number of workers available in any period is

$$\text{Number of workers in a period} = \text{Number of workers at end of the previous period} + \text{Number of new workers at start of the period} - \text{Number of laid-off workers at start of the period}$$

Note: An organization would not hire and lay off simultaneously, so at least one of the last two terms will equal zero.

The amount of inventory at the end of a given period is

$$\text{Inventory at the end of a period} = \text{Inventory at end of the previous period} + \text{Production in the current period} - \text{Amount used to satisfy demand in the current period}$$

The average inventory for a period is equal to

$$\frac{\text{Beginning inventory} + \text{Ending inventory}}{2}$$

The cost of a particular plan for a given period can be determined by summing the appropriate costs:

$$\text{Cost for a period} = \text{Output cost (Reg + OT + Subcontract)} + \text{Hire/lay off cost} + \text{Inventory cost} + \text{Back-order cost}$$

The appropriate costs are calculated as follows:

Type of Cost	How to Calculate
Output	
Regular	Regular cost per unit × Quantity of regular output
Overtime	Overtime cost per unit × Overtime quantity
Subcontract	Subcontract cost per unit × Subcontract quantity
Hire/lay off	
Hire	Cost per hire × Number hired
Lay off	Cost per layoff × Number laid off
Inventory	Carrying cost per unit × Average inventory
Back order	Back-order cost per unit × Number of back-order units

The following examples are only two of many possible options that could be tried. Perhaps some of the others would result in a lower cost. With trial and error, you can never be completely sure you have identified the lowest-cost alternative unless every possible alternative is evaluated. Of course, the purpose of these examples is to illustrate the process of developing and evaluating an aggregate plan rather than to find the lowest-cost plan. Problems at the end of the chapter cover still other alternatives.

In practice, successful achievement of a good plan depends on the resourcefulness and persistence of the planner. Computer software such as the Excel templates that accompany this book can eliminate the computational burden of trial-and-error techniques.

EXAMPLE 1

Planners for a company that makes several models of skateboards are about to prepare the aggregate plan that will cover six periods. They have assembled the following information:

Period	1	2	3	4	5	6	Total
Forecast	200	200	300	400	500	200	1,800

Costs

Output	
Regular time	= $2 per skateboard
Overtime	= $3 per skateboard
Subcontract	= $6 per skateboard
Inventory	= $1 per skateboard per period on average inventory
Back orders	= $5 per skateboard per period

They now want to evaluate a plan that calls for a steady rate of regular-time output, mainly using inventory to absorb the uneven demand but allowing some backlog. Overtime and subcontracting are not used because they want steady output. They intend to start with zero inventory on hand in the first period. Prepare an aggregate plan and determine its cost using the preceding information. Assume a level output rate of 300 units (skateboards) per period with regular time (i.e., 1,800/6 = 300). Note that the planned ending inventory is zero. There are 15 workers, and each can produce 20 skateboards per period.

SOLUTION

Period	1	2	3	4	5	6	Total
Forecast	200	200	300	400	500	200	1,800
Output							
Regular	300	300	300	300	300	300	1,800
Overtime	—	—	—	—	—	—	
Subcontract	—	—	—	—	—	—	
Output − Forecast	100	100	0	(100)	(200)	100	0
Inventory							
Beginning	0	100	200	200	100	0	
Ending	100	200	200	100	0	0	
Average	50	150	200	150	50	0	600
Backlog	0	0	0	0	100	0	100

Period	1	2	3	4	5	6	Total
Costs							
Output							
Regular	$600	600	600	600	600	600	$3,600
Overtime	—	—	—	—	—	—	
Subcontract	—	—	—	—	—	—	
Hire/Lay off	—	—	—	—	—	—	
Inventory	$ 50	150	200	150	50	0	$ 600
Back orders	$ 0	0	0	0	500	0	$ 500
Total	$650	750	800	750	1,150	600	$4,700

Note that the total regular-time output of 1,800 units equals the total expected demand. Ending inventory equals beginning inventory plus or minus the quantity Output − Forecast. If Output − Forecast is negative, inventory is decreased in that period by that amount. If insufficient inventory exists, a backlog equal to the shortage amount appears, as in period 5. This is taken care of using the excess output in period 6.

The costs were computed as follows. Regular cost in each period equals 300 units × $2 per unit or $600. Inventory cost equals average inventory × $1 per unit. Back-order cost is $5 per unit. The total cost for this plan is $4,700.

Note that the first two quantities in each column are givens. The remaining quantities in the upper portion of the table were determined working down each column, beginning with the first column. The costs were then computed based on the quantities in the upper part of the table.

EXAMPLE 2

After reviewing the plan developed in the preceding example, planners have decided to develop an alternative plan. They have learned that one person is about to retire from the company. Rather than replace that person, they would like to stay with the smaller workforce and use overtime to make up for the lost output. The reduced regular-time output is 280 units per period. The maximum amount of overtime output per period is 40 units. Develop a plan and compare it to the previous one.

SOLUTION

Period	1	2	3	4	5	6	Total
Forecast	200	200	300	400	500	200	1,800
Output							
Regular	280	280	280	280	280	280	1,680
Overtime	0	0	40	40	40	0	120
Subcontract	—	—	—	—	—	—	
Output − Forecast	80	80	20	(80)	(180)	80	0
Inventory							
Beginning	0	80	160	180	100	0	
Ending	80	160	180	100	0	0	
Average	40	120	170	140	50	0	520
Backlog	0	0	0	0	80	0	80
Costs							
Output							
Regular	$560	560	560	560	560	560	$3,360
Overtime	0	0	120	120	120	0	$ 360
Subcontract	—	—	—	—	—	—	
Hire/Lay off	—	—	—	—	—	—	
Inventory	40	120	170	140	50	0	$ 520
Back orders	$0	0	0	0	400	0	$ 400
Total	$600	680	850	820	1,130	560	$4,640

The amount of overtime that must be scheduled has to make up for lost output of 20 units per period for six periods, which is 120. This is scheduled toward the center of the planning horizon since that is where the bulk of demand occurs. Scheduling it earlier would increase inventory carrying costs; scheduling it later would increase the backlog cost.

Overall, the total cost for this plan is $4,640, which is $60 less than the previous plan. Regular-time production cost and inventory cost are down, but there is overtime cost. However, this plan achieves savings in back-order cost, making it somewhat less costly overall than the plan in Example 1.

Mathematical Techniques

A number of mathematical techniques have been developed to handle aggregate planning. They range from mathematical programming models to heuristic and computer search models. This section briefly describes some of the better-known techniques.

Linear Programming Linear programming models are methods for obtaining optimal solutions to problems involving the allocation of scarce resources in terms of cost minimization or profit maximization. With aggregate planning, the goal is usually to minimize the sum of costs related to regular labor time, overtime, subcontracting, carrying inventory, and costs associated with changing the size of the workforce. Constraints involve the capacities of the workforce, inventories, and subcontracting.

The problem can be formulated as a transportation-type programming model (described in detail in the supplement to Chapter 8) as a way to obtain aggregate plans that would match capacities with demand requirements and minimize costs. In order to use this approach, planners must identify capacity (supply) of regular time, overtime, subcontracting, and inventory on a period-by-period basis, as well as related costs of each variable.

Table 12.5 shows the notation and setup of a transportation table. Note the systematic way that costs change as you move across a row from left to right. Regular cost, overtime cost, and

TABLE 12.5 Transportation notation for aggregate planning

Period		Period 1	Period 2	Period 3	. . .	Ending inventory period n	Unused capacity	Capacity
	Beginning inventory	0	h	$2h$	. . .	$(n-1)h$	0	I_0
1	Regular time	r	$r+h$	$r+2h$	. . .	$r+(n-1)h$	0	R_1
	Overtime	t	$t+h$	$t+2h$	. . .	$t+(n-1)h$	0	O_1
	Subcontract	s	$s+h$	$s+2h$	. . .	$s+(n-1)h$	0	S_1
2	Regular time	$r+b$	r	$r+h$	. . .	$r+(n-2)h$	0	R_2
	Overtime	$t+b$	t	$t+h$	. . .	$t+(n-2)h$	0	O_2
	Subcontract	$s+b$	s	$s+h$	. . .	$s+(n-2)h$	0	S_2
3	Regular time	$r+2b$	$r+b$	r	. . .	$r+(n-3)h$	0	R_3
	Overtime	$t+2b$	$t+b$	t	. . .	$t+(n-3)h$	0	O_3
	Subcontract	$s+2b$	$s+b$	s	. . .	$s+(n-3)h$	0	S_3
	Demand				. . .			Total

r = Regular production cost per unit
t = Overtime cost per unit
s = Subcontracting cost per unit
h = Holding cost per unit period
b = Backorder cost per unit per period
n = Number of periods in planning horizon

subcontracting cost are at their lowest when the output is consumed (i.e., delivered, etc.) in the same period it is produced (at the intersection of period 1 row and column for regular cost, at the intersection of period 2 row and column for regular cost, and so on). If goods are made available in one period but carried over to later periods (i.e., moving across a row), holding costs are incurred at the rate of h per period. Thus, holding goods for two periods results in a unit cost of $2h$, whether or not the goods came from regular production, overtime, or subcontracting. Conversely, with back orders, the unit cost increases as you move across a row from right to left, beginning at the intersection of a row and column for the same period (e.g., period 3). For instance, if some goods are produced in period 3 to satisfy back orders from period 2, a unit back-order cost of b is incurred. And if goods in period 3 are used to satisfy back orders two periods earlier (e.g., from period 1), a unit cost of $2b$ is incurred. Unused capacity is generally given a unit cost of 0, although it is certainly possible to insert an actual cost if that is relevant. Finally, beginning inventory is given a unit cost of 0 if it is used to satisfy demand in period 1. However, if it is held over for use in later periods, a holding cost of h per unit is added for each period. If the inventory is to be held for the entire planning horizon, a total unit cost of h times the number of periods, n, will be incurred.

Example 3 illustrates the setup and final solution of a transportation model of an aggregate planning problem.

EXAMPLE 3

Given the following information set up the problem in a transportation table and solve for the minimum-cost plan:

	PERIOD		
	1	2	3
Demand	550	700	750
Capacity			
Regular	500	500	500
Overtime	50	50	50
Subcontract	120	120	100
Beginning inventory	100		
Costs			
Regular time		$60 per unit	
Overtime		80 per unit	
Subcontract		90 per unit	
Inventory carrying cost		$1 per unit per month	
Back-order cost		$3 per unit per month	

SOLUTION

The transportation table and solution are shown in Table 12.6. Some of the entries require additional explanation:

a. In this example, inventory carrying costs are $1 per unit per period (costs are shown in the upper right-hand corner of each cell in the table). Hence, units produced in one period and carried over to a later period will incur a holding cost that is a linear function of the length of time held.

b. Linear programming models of this type require that supply (capacity) and demand be equal. A dummy column has been added (nonexistant capacity) to satisfy that requirement. Since it does not "cost" anything extra to not use capacity in this case, cell costs of $0 have been assigned.

c. No backlogs were needed in this example.

d. The quantities (e.g., 100 and 450 in column 1) are the amounts of output or inventory that will be used to meet demand requirements. Thus, the demand of 550 units in period 1 will be met using 100 units from inventory and 450 obtained from regular-time output.

TABLE 12.6
Transportation solution

	Supply from	Demand for: Period 1	Period 2	Period 3	Unused capacity (dummy)	Total capacity available (supply)
Period	Beginning inventory	[0] 100	[1]	[2]	[0]	100
1	Regular time	[60] 450	[61] 50	[62]	[0]	500
	Overtime	[80]	[81] 50	[82]	[0]	50
	Subcontract	[90]	[91] 30	[92]	[0] 90	120
2	Regular time	[63]	[60] 500	[61]	[0]	500
	Overtime	[83]	[80] 50	[81]	[0]	50
	Subcontract	[93]	[90] 20	[91] 100	[0]	120
3	Regular time	[66]	[63]	[60] 500	[0]	500
	Overtime	[86]	[83]	[80] 50	[0]	50
	Subcontract	[96]	[93]	[90] 100	[0]	100
	Demand	550	700	750	90	2,090

Where backlogs are not permitted, the cell costs for the backlog positions can be made prohibitively high so that no backlogs will appear in the solution.

The main limitations of LP models are the assumptions of linear relationships among variables, the inability to continuously adjust output rates, and the need to specify a single objective (e.g., minimize costs) instead of using multiple objectives (e.g., minimize cost while stabilizing the workforce.)

Linear Decision Rule Another optimizing technique, the **linear decision rule,** seeks to minimize the combined costs of regular payroll, hiring and layoffs, overtime, and inventory using a set of cost-approximating functions, three of which are *quadratic* (contain squared terms), to obtain a single quadratic equation. Using calculus, two linear equations (hence, the name *linear decision rule*) can be derived from the quadratic equation. One of these equations can be used to plan the output for each period in the planning horizon, and the other can be used to plan the workforce for each period.

linear decision rule Optimizing technique that seeks to minimize combined costs, using a set of cost-approximating functions to obtain two linear equations.

Although the model has found some applications, its chief function seems to be as a benchmark against which proposed techniques can be evaluated. In practice, the model suffers from three limitations: (1) a specific type of cost function is assumed, (2) considerable effort must usually be expended to obtain relevant cost data and develop cost functions for each organization, and (3) the method can produce solutions that are unfeasible or impractical.

simulation models Computerized models that can be tested under different scenarios to identify acceptable solutions to problems.

Simulation Models A number of **simulation models** have been developed for aggregate planning. (Simulation is described in detail in the supplement to Chapter 18.) The essence of simulation is the development of computerized models that can be tested under a variety of

TABLE 12.7
Summary of planning techniques

Technique	Solution Approach	Characteristics
Spreadsheet	Trial and error	Intuitively appealing, easy to understand; solution not necessarily optimal
Linear programming	Optimizing	Computerized; linear assumptions not always valid
Linear decision rule	Optimizing	Complex, requires considerable effort to obtain pertinent cost information and to construct model; cost assumptions not always valid
Simulation	Trial and error	Computerized models can be examined under a variety of conditions

conditions in an attempt to identify reasonably acceptable (although not always optimal) solutions to problems.

Table 12.7 summarizes these mathematical techniques.

Aggregate planning techniques other than trial and error do not appear to be widely used. Instead, in the majority of organizations, aggregate planning seems to be accomplished more on the basis of experience along with trial-and-error methods. It is difficult to say exactly why some of the mathematical techniques mentioned are not used to any great extent. Perhaps the level of mathematical sophistication discourages greater use; or the assumptions required in certain models appear unrealistic; or the models may be too narrow in scope. Whatever the reasons, none of the techniques to date have captured the attention of aggregate planners on a broad scale. Simulation is one technique that seems to be gaining favor. Research on improved approaches to aggregate planning is continuing.

AGGREGATE PLANNING IN SERVICES

S

Aggregate planning for services takes into account projected customer demands, equipment capacities, and labor capabilities. The resulting plan is a time-phased projection of service staff requirements.

Aggregate planning for manufacturing and aggregate planning for services share similarities in some respects, but there are some important differences—related in general to the differences between manufacturing and services:

1. *Services occur when they are rendered.* Unlike manufacturing output, most services can't be inventoried. Services such as financial planning, tax counseling, and oil changes can't be stockpiled. This removes the option of building up inventories during a slow period in anticipation of future demand. Moreover, service capacity that goes unused is essentially wasted. Consequently, it becomes even more important to be able to match capacity and demand.

2. *Demand for service can be difficult to predict.* The volume of demand for services is often quite variable. In some situations, customers may *need* prompt service (e.g., police, fire, medical emergency), while in others, they simply *want* prompt service and may be willing to go elsewhere if their wants are not met. These factors place a greater burden on service providers to anticipate demand. Consequently, service providers must pay careful attention to planned capacity levels.

3. *Capacity availability can be difficult to predict.* Processing requirements for services can sometimes be quite variable, similar to the variability of work in a job shop setting. Moreover, the variety of tasks required of servers can be great, again similar to the variety of tasks in a job shop. However, in services, the types of variety are more pervasive than they are in manufacturing. This makes it more difficult to establish simple measures of capacity. For example, what would be the capacity of a person who paints interiors of houses? The number of rooms per day

or the number of square feet per hour are possible measures, but rooms come in many different sizes, and because the level of detail (and, thus, the painting implements that can be used) vary tremendously, a suitable measure for planning purposes can be quite difficult to arrive at. Similarly, bank tellers are called upon to handle a wide variety of transactions and requests for information, again making it difficult to establish a suitable measure of their capacity.

4. *Labor flexibility can be an advantage in services.* Labor often comprises a significant portion of service compared to manufacturing. That, coupled with the fact that service providers are often able to handle a fairly wide variety of service requirements, means that to some extent, planning is easier than it is in manufacturing. Of course, manufacturers recognize this advantage, and many are cross-training their employees to achieve the same flexibility. Moreover, in both manufacturing and service systems, the use of part-time workers can be an important option.

In self-service systems, the (customer) labor automatically adjusts to changes in demand!

DISAGGREGATING THE AGGREGATE PLAN

For the production plan to be translated into meaningful terms for production, it is necessary to *disaggregate* the aggregate plan. This means breaking down the aggregate plan into specific product requirements in order to determine labor requirements (skills, size of workforce), materials, and inventory requirements. This process is described in Chapter 13. At this stage, however, it will be helpful for you to have some understanding of the need for disaggregation and what the term implies.

Working with aggregate units facilitates intermediate planning. However, to put the production plan into operation, one must convert, or decompose, those aggregate units into units of actual products or services that are to be produced or offered. For example, a lawn mower manufacturer may have an aggregate plan that calls for 200 lawn mowers in January, 300 in February, and 400 in March. That company may produce push mowers, self-propelled mowers, and riding mowers. Although all the mowers probably contain some of the same parts and involve some similar or identical operations for fabrication and assembly, there would be some differences in the materials, parts, and operations that each type requires. Hence, the 200, 300, and 400 aggregate lawn mowers that are to be produced during those three months must be translated into specific numbers of mowers of each type prior to actually purchasing the appropriate materials and parts, scheduling operations, and planning inventory requirements.

The result of disaggregating the aggregate plan is a **master schedule** showing the quantity and timing of *specific* end items for a scheduled horizon, which often covers about six to eight weeks ahead. A master schedule shows the planned output for individual products rather than an entire product group, along with the timing of production. The master schedule contains important information for marketing as well as for production. It reveals when orders are scheduled for production and when completed orders are to be shipped.

master schedule Shows quantity and timing of specific end items for a scheduled horizon.

Figure 12.4 shows an overview of the context of disaggregation.

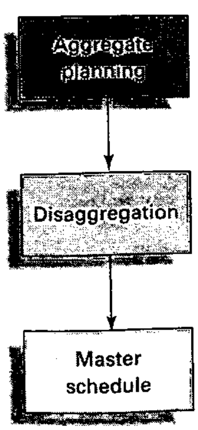


FIGURE 12.4

Moving from the aggregate plan to a master schedule

FIGURE 12.5

Disaggregating the aggregate plan

Aggregate plan

Month	***Jan.***	***Feb.***	***Mar.***
Planned output*	200	300	400

**Aggregate units*

Master schedule

Month	***Jan.***	***Feb.***	***Mar.***
Planned output*			
Push	100	100	100
Self-propelled	75	150	200
Riding	25	50	100
Total	200	300	400

**Actual units*

Figure 12.5 illustrates disaggregating the aggregate plan. The illustration makes a simple assumption in order to clearly show the concept of disaggregation: The totals of the aggregate and the disaggregated units are equal. In reality, that is not always true. As a consequence, disaggregating the aggregate plan may require considerable effort.

Figure 12.5 shows the aggregate plan broken down by units. However, it also can be useful to show the breakdown in *percentages* for different products or product families.

MASTER SCHEDULING

The master schedule is the heart of production planning and control. It determines the quantities needed to meet demand from all sources, and that governs key decisions and activities throughout the organization.

The master schedule interfaces with marketing, capacity planning, production planning, and distribution planning: It enables marketing to make valid delivery commitments to warehouses and final customers; it enables production to evaluate capacity requirements; it provides the necessary information for production and marketing to negotiate when customer requests cannot be met by normal capacity; and it provides senior management with the opportunity to determine whether the business plan and its strategic objectives will be achieved. The master schedule also drives the material requirements planning (MRP) system that will be discussed in the next chapter.

The central person in the master scheduling process is the master scheduler.

The Master Scheduler

Most manufacturing organizations have (or should have) a master scheduler. The duties of the master scheduler generally include

1. Evaluating the impact of new orders.
2. Providing delivery dates for orders.
3. Dealing with problems:
   a. Evaluating the impact of production delays or late deliveries of purchased goods.
   b. Revising the master schedule when necessary because of insufficient supplies or capacity.
   c. Bringing instances of insufficient capacity to the attention of production and marketing personnel so that they can participate in resolving conflicts.

THE MASTER SCHEDULING PROCESS

A master schedule indicates the quantity and timing (i.e., delivery times) for a product, or a group of products, but it does not show planned *production.* For instance, a master schedule may call for delivery of 50 cases of cranberry-apple juice to be delivered on May 1. But this may not require any production; there may be 200 cases in inventory. Or it may require *some*

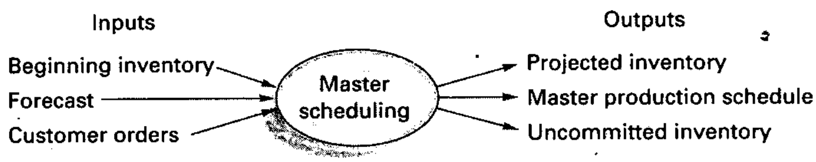


FIGURE 12.6
The master scheduling process

production: If there were 40 cases in inventory, an additional 10 cases would be needed to achieve the specified delivery amount. Or it may involve production of 50 or more cases: In some instances, it is more economical to produce large amounts rather than small amounts, with the excess temporarily placed in inventory until needed. Thus, the *production lot size* might be 70 cases, so if additional cases were needed (e.g., 50 cases), a run of 70 cases would be made.

The **master production schedule (MPS)** indicates the quantity and timing of planned production, taking into account desired delivery quantity and timing as well as on-hand inventory. The master production schedule is one of the primary outputs of the master scheduling process, as illustrated in Figure 12.6.

master production schedule (MPS) This schedule indicates the quantity and timing of planned completed production.

Once a *tentative* master schedule has been developed, it must be validated. This is an extremely important step. Validation is referred to as **rough-cut capacity planning (RCCP).** It involves testing the feasibility of a proposed master schedule relative to available capacities, to assure that no obvious capacity constraints exist. This means checking capacities of production and warehouse facilities, labor, and vendors to ensure that no gross deficiencies exist that will render the master schedule unworkable. The master production schedule then serves as the basis for *short-range* planning. It should be noted that whereas the aggregate plan covers an interval of, say, 12 months, the master schedule covers only a portion of this. In other words, the aggregate plan is disaggregated in stages, or phases, that may cover a few weeks to two or three months. Moreover, the master schedule may be updated monthly, even though it covers two or three months. For instance, the lawn mower master schedule would probably be updated at the end of January to include any revisions in planned output for February and March as well as new information on planned output for April.

rough-cut capacity planning Approximate balancing of capacity and demand to test the feasibility of a master schedule.

Inputs

The master schedule has three inputs: the beginning inventory, which is the actual quantity on hand from the preceding period; forecasts for each period of the schedule; and customer orders, which are quantities already *committed* to customers.

Outputs

The master scheduling process uses this information on a period-by-period basis to determine the projected inventory, production requirements, and the resulting uncommitted inventory, which is referred to as **available-to-promise (ATP) inventory.** Knowledge of the uncommitted inventory can enable marketing to make realistic promises to customers about deliveries of new orders.

available-to-promise (ATP) inventory Uncommitted inventory.

The master scheduling process begins with a preliminary calculation of projected on-hand inventory. This reveals when additional inventory (i.e., production) will be needed. Consider this example. A company that makes industrial pumps wants to prepare a master production schedule for June and July. Marketing has forecasted demand of 120 pumps for June and 160 pumps for July. These have been evenly distributed over the four weeks in each month: 30 per week in June and 40 per week in July, as illustrated in Figure 12.7a.

Now, suppose that there are currently 64 pumps in inventory (i.e., beginning inventory is 64 pumps), and that there are customer orders that have been committed (booked) and must be filled (see Figure 12.7b).

Figure 12.7b contains the three primary inputs to the master scheduling process: the beginning inventory, the forecast, and the customer orders that have been booked or committed. This information is necessary to determine three quantities: the projected on-hand inventory, the master production schedule, and the uncommitted (ATP) inventory. The first step is to calculate

FIGURE 12.7A

Weekly forecast requirements for industrial pumps.

	June				July			
	1	2	3	4	5	6	7	8
Forecast	30	30	30	30	40	40	40	40

FIGURE 12.7B

Eight-week schedule showing forecasts, customer orders, and beginning inventory

Beginning inventory	June				July			
64	1	2	3	4	5	6	7	8
Forecast	30	30	30	30	40	40	40	40
Customer orders (committed)	33	20	10	4	2			

FIGURE 12.8

Projected on-hand inventory is computed week by week until it becomes negative

Beginning inventory	June				July			
64	1	2	3	4	5	6	7	8
Forecast	30	30	30	30	40	40	40	40
Customer orders (committed)	33	20	10	4	2			
Projected on-hand inventory	31	1	−29					

Customer orders are larger than forecast in week 1; projected on-hand inventory is 64 − 33 = 31

Forecast is larger than customer orders in week 2; projected on-hand inventory is 31 − 30 = 1

Forecast is larger than customer orders in week 3; projected on-hand inventory is 1 − 30 = −29

the projected on-hand inventory, one week at a time, until it falls below a specified limit. In this example, the specified limit will be zero. Hence, we will continue until the projected on-hand inventory becomes negative.

The projected on-hand inventory is calculated as follows:

$$\text{Projected on-hand inventory} = \text{Inventory from previous week} - \text{Current week's requirements} \tag{12–1}$$

where the current week's requirements are the *larger* of forecast and customer orders (committed).

For the first week, projected on-hand inventory equals beginning inventory minus the larger of forecast and customer orders. Because customer orders (33) are larger than the forecast (30), the customer orders amount is used. Thus, for the first week, we obtain

$$\text{Projected on-hand inventory} = 64 - 33 = 31$$

Projected on-hand inventories are shown in Figure 12.8 for the first three weeks (i.e., until the projected on-hand amount becomes negative).

Week	Inventory from Previous Week	Requirements*	Net Inventory before MPS		(70) MPS		Projected Inventory
1	64	33	31				31
2	31	30	1				1
3	1	30	−29	+	70	=	41
4	41	30	11				11
5	11	40	−29	+	70	=	41
6	41	40	1				1
7	1	40	−39	+	70	=	31
8	31	40	−9	+	70	=	61

*Requirements equals the larger of forecast and customer orders in each week.

FIGURE 12.9

Determining the MPS and projected on-hand inventory

	June				July			
64	1	2	3	4	5	6	7	8
Forecast	30	30	30	30	40	40	40	40
Customer orders (committed)	33	20	10	4	2			
Projected on-hand inventory	31	1	41	11	41	1	31	61
MPS			70		70		70	70

FIGURE 12.10

Projected on-hand inventory and MPS are added to the master schedule

When the projected on-hand inventory becomes negative, this is a signal that production will be needed to replenish inventory. Hence, a negative projected on-hand inventory will require planned production. Suppose that a production lot size of 70 pumps is used, so that whenever production is called for, 70 pumps will be produced. (The determination of lot size was described in Chapter 11.) Hence, the negative projected on-hand inventory in the third week will require production of 70 pumps, which will meet the projected shortfall of 29 pumps and leave 41 (i.e., $70 - 29 = 41$) pumps for future demand.

These calculations continue for the entire schedule. Every time projected inventory becomes negative, another production lot of 70 pumps is added to the schedule. Figure 12.9 illustrates the calculations. The result is the master schedule and projected on-hand inventory for each week of the schedule. These can now be added to the master schedule (see Figure 12.10).

It is now possible to determine the amount of inventory that is uncommitted, and, hence, available to promise. Several methods are used in practice. The one we shall employ involves a "look-ahead" procedure: Sum booked customer orders week by week until (but not including) a week in which there is an MPS amount. For example, in the first week, this procedure results in summing customer orders of 33 (week 1) and 20 (week 2) to obtain 53. In the first week, this amount is subtracted from the beginning inventory of 64 pumps plus the MPS (zero in this example) to obtain the amount that is available to promise. Thus,

$$64 + 0 - (33 + 20) = 11$$

This inventory is uncommitted, and it can be delivered in either week 1 or 2, or part can be delivered in week 1 and part in week 2. (Note that the ATP quantity is only calculated for the first

FIGURE 12.11

The available-to-promise inventory quantities have been added to the master schedule

	June				July			
64	1	2	3	4	5	6	7	8
Forecast	30	30	30	30	40	40	40	40
Customer orders (committed)	33	20	10	4	2			
Projected on-hand inventory	31	1	41	11	41	1	31	61
MPS			70		70		70	70
Available-to-promise inventory (uncommitted)	11		56		68		70	70

week and for other weeks in which there is an MPS quantity. Hence, it is calculated for weeks 1, 3, 5, 7, 8.) See Figure 12.11.

For weeks other than the first week, the beginning inventory drops out of the computation, and ATP is the look-ahead quantity subtracted from the MPS quantity.

Thus, for week 3, the promised amounts are $10 + 4 = 14$, and the ATP is $70 - 14 = 56$.

For week 5, customer orders are 2 (future orders have not yet been booked). The ATP is $70 - 2 = 68$.

For weeks 7 and 8, there are no customer orders, so for the present, all of the MPS amount is available to promise.

As additional orders are booked, these would be entered in the schedule, and the ATP amounts would be updated to reflect those orders. Marketing can use the ATP amounts to provide realistic delivery dates to customers.

Time Fences

Changes to a master schedule can be disruptive, particularly changes to the early, or near, portions of the schedule. Typically, the further out in the future a change is, the less the tendency to cause problems.

High-performance organizations have an effective master scheduling process. A key component of effective scheduling is the use of *time fences* to facilitate order promising and the entry of orders into the system. **Time fences** divide a scheduling time horizon into three sections or phases, sometimes referred to as *frozen, slushy,* and *liquid,* in reference to the firmness of the schedule (see Figure 12.12).

time fences Points in time that separate phases of a master schedule planning horizon.

Frozen is the near-term phase that is so soon that delivery of a new order would be impossible, or only possible using very costly or extraordinary options such as delaying another order. Authority for new-order entry in this phase usually lies with the VP of manufacturing. The length of the frozen phase is often a function of the total time needed to produce a product, from procuring materials to shipping the order. There is a high degree of confidence in order-promise dates.

Slushy is the next phase, and its time fence is usually a few periods beyond the frozen phase. Order entry in this phase necessitates trade-offs, but is less costly or disruptive than in the frozen phase. Authority for order entry usually lies with the master scheduler. There is relative confidence in order-promise dates.

Liquid is the farthest out on the time horizon. New orders or cancellations can be entered with ease. Order promise dates are tentative, and will be firmed up with the passage of time when orders are in the firm phase of the schedule horizon.

A key element in the success of the master scheduling process is strict adherence to time fence policies and rules. It is essential that they be adhered to and communicated throughout the organization.

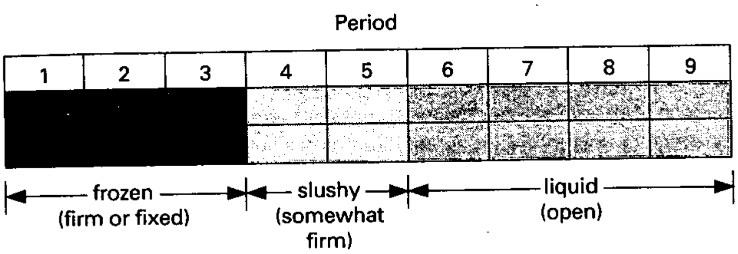


FIGURE 12.12

Time fences in an MPS

SUMMARY

Aggregate planning establishes general levels of employment, output, and inventories for periods of 2 to 12 months. In the spectrum of planning, it falls between the broad decisions of long-range planning and the very specific and detailed short-range planning decisions. It begins with an overall forecast for the planning horizon and ends with preparations for applying the plans to specific products and services.

The essence of aggregate planning is the aggregation of products or services into one "product" or "service." This permits planners to consider overall levels of employment and inventories without having to become involved with specific details that are better left to short-range planning. Planners often use informal graphic and charting techniques to develop plans, although various mathematical techniques have been suggested. It appears that the complexity and the restrictive assumptions of these techniques limit their widespread use in practice.

After the aggregate plan has been developed, it is disaggregated or broken down into specific product requirements. This leads to a master schedule, which indicates the planned quantities and timing of specific outputs. Inputs to the master schedule are on-hand inventory amounts, forecasts of demand, and customer orders. The outputs are projected production and inventory requirements, and the projected uncommitted inventory, which is referred to as available-to-promise (ATP) inventory.

The aggregate planning process is summarized in Table 12.8.

KEY TERMS

aggregate planning, 541
available-to-promise (ATP) inventory, 561
chase demand strategy, 548
level capacity strategy, 548
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SOLVED PROBLEMS

Problem 1

A manager is attempting to put together an aggregate plan for the coming nine months. She has obtained a forecast of expected demand for the planning horizon. The plan must deal with highly seasonal demand; demand is relatively high in periods 3 and 4 and again in period 8, as can be seen from the following forecasts:

Period	1	2	3	4	5	6	7	8	9	Total
Forecast	190	230	260	280	210	170	160	260	180	1,940

The department now has 20 full-time employees, each of whom can produce 10 units of output per period at a cost of $6 per unit. Inventory carrying cost is $5 per unit per period, and backlog cost is $10 per unit per period. The manager is considering a plan that would involve hiring two people to start working in period 1, one on a temporary basis who would work only through period 5. This would cost $500 in addition to unit production costs.

a. What is the rationale for this plan?

b. Determine the total cost of the plan, including production, inventory, and back-order costs.

Solution

a. With the current workforce of 20 people each producing 10 units per period, regular capacity is 1,800 units. That is 140 units less than expected demand. Adding one worker would increase regular capacity to 1,800 + 90 = 1,890 units. That would still be 50 units short, or just the amount one temporary worker could produce in five periods. Since one of the two seasonal peaks is quite early, it would make sense to start the temporary worker right away to avoid some of the back-order cost.

b. The production plan for this strategy is as follows:

Period	1	2	3	4	5	6	7	8	9	Total
Forecast	190	230	260	280	210	170	160	260	180	1,940
Output										
Regular	220	220	220	220	220	210	210	210	210	1,940
Overtime	—	—	—	—	—	—	—	—	—	—
Subcontract	—	—	—	—	—	—	—	—	—	—
Output−Forecast	30	(10)	(40)	(60)	10	40	50	(50)	30	0
Inventory										
Beginning	0	30	20	0	0	0	0	20	0	
Ending	30	20	0	0	0	0	20	0	0	
Average	15	25	10	0	0	0	10	10	0	70
Backlog	0	0	20	80	70	30	0	30	0	230

TABLE 12.8
Summary of aggregate planning

Purpose
Decide on the combination of
- Output rates
- Employment levels
- On-hand inventory levels

Objectives
- Minimize cost
- Others, may include
  - Maintain a desirable level of customer service
  - Minimize workforce fluctuations

Possible Strategies

A. Supply Management (reactive)

Level Production
- Allow inventory to absorb variations in demand
- Use back ordering during periods of high demand

Chase Production
- Vary output by varying the number of workers by hiring or layoffs to track demand
- Vary output throughout the use of overtime or idle time
- Vary output using part-time workers
- Use subcontracting to supplement output

Mixed Strategy
- Use a combination of level and chase approaches

B. Demand Management (proactive)
- Influence demand through promotion, pricing, etc.
- Produce goods or services that have complementary demand patterns

Managerial Importance of Aggregate Planning
Has an effect on
- Costs
- Equipment utilization
- Customer satisfaction
- Employment levels
- Synchronization of flow throughout the supply chain

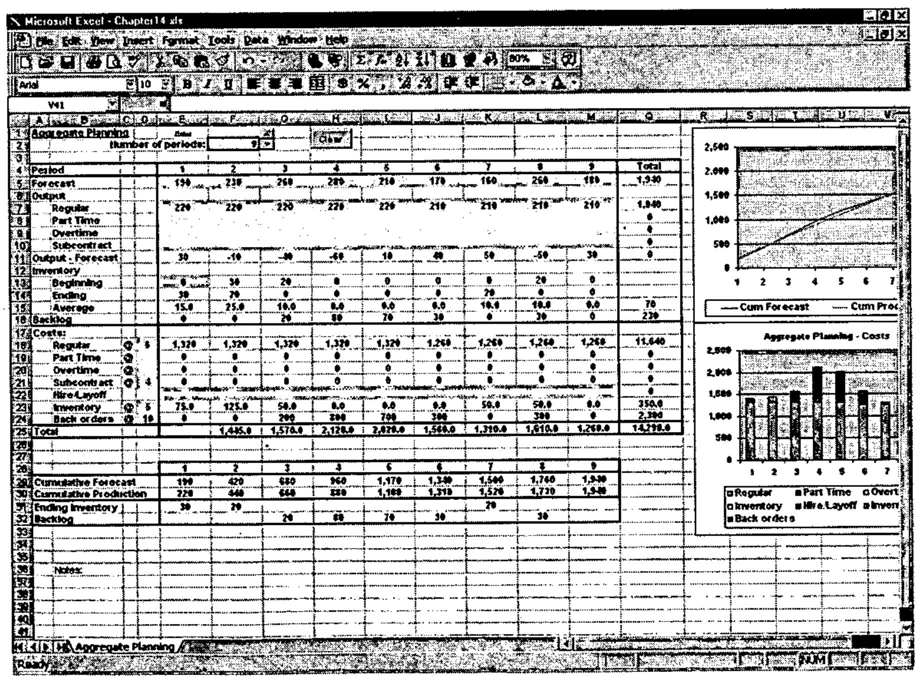
Costs										
Output										
Regular @ $6	$1,320	1,320	1,320	1,320	1,320	1,260	1,260	1,260	1,260	$11,640
Overtime										
Subcontract										
Inventory @ $5	$75	125	50	0	0	0	50	50	0	$350
Backorder @ $10	0	0	200	800	700	300	0	300	0	$2,300
Total	$1,395	1,445	1,570	2,120	2,020	1,560	1,310	1,610	1,260	$14,290

The total cost for this plan is $14,290, plus the $500 cost for hiring and for the layoff, giving a total of $14,790. This plan may or may not be good. The manager would need information on other costs and options before settling on one plan.

Although the calculations are relatively straightforward, the backlogs can sometimes seem difficult to obtain. Consider these rules for computing the backlog:

1. Start with the Output − Forecast value. If this is positive and there was a backlog in the preceding period, reduce the backlog by this amount. If the amount exceeds the backlog, the difference becomes the ending inventory for the period. If they are exactly equal, the backlog and the ending inventory will both be equal to zero.
2. If Output − Forecast is negative, subtract it from the beginning inventory. If this produces a negative value, that value becomes the backlog for that period.

You also can use the appropriate Excel template to obtain the solution:



Excel

Problem 2

Prepare a schedule like that shown in Figure 12.10 for the following situation. The forecast for each period is 70 units. The starting inventory is zero. The MPS rule is to schedule production if the projected inventory on hand is negative. The production lot size is 100 units. The following table shows committed orders.

Period	Customer Orders
1	80
2	50
3	30
4	10

Solution

Period	(A) Inventory from Previous Period	(B) Requirements*	(C = B − A) Net Inventory before MPS	MPS	(MPS + C) Projected Inventory
1	0	80	(80)	100	20
2	20	70	(50)	100	50
3	50	70	(20)	100	80
4	80	70	10	0	10

*Requirements equal the larger of forecast and customer orders in each period.

Starting Inv. = 0	1	2	3	4
Forecast	70	70	70	70
Customer orders	80	50	30	10
Projected on-hand inventory	20	50	80	10
MPS	100	100	100	0
ATP	20	50	60	0

DISCUSSION AND REVIEW QUESTIONS

1. What three levels of planning involve operations managers? What kinds of decisions are made at the various levels?
2. What are the three phases of intermediate planning?
3. What is aggregate planning? What is its purpose?
4. Why is there a need for aggregate planning?
5. What are the most common decision variables for aggregate planning in a manufacturing setting? In a service setting?
6. What aggregate planning difficulty that might confront an organization offering a variety of products and/or services would not confront an organization offering one or a few similar products or services?
7. Briefly discuss the advantages and disadvantages of each of these planning strategies:
   a. Maintain a level rate of output and let inventories absorb fluctuations in demand.
   b. Vary the size of the workforce to correspond to predicted changes in demand requirements.
   c. Maintain a constant workforce size, but vary hours worked to correspond to predicted demand requirements.
8. What are the primary advantages and limitations of informal graphic and charting techniques for aggregate planning?
9. Briefly describe the planning techniques listed below, and give an advantage and disadvantage for each:
   a. Linear programming
   b. Linear decision rule
   c. Simulation
10. What are the inputs to master scheduling? What are the outputs?
11. Explain the managerial significance of aggregate planning.

TAKING STOCK

1. What general trade-offs are involved in master scheduling in terms of the frozen portion of the schedule?
2. Who needs to interface with the master schedule and why?
3. How has technology had an impact on master scheduling?

CRITICAL THINKING EXERCISE

Service operations often face more difficulty in planning than their manufacturing counterparts. However, service does have certain advantages that manufacturing often does not. Explain service planning difficulty, and the advantages.

PROBLEMS

1. Refer to Example 1. The president of the firm has decided to shut down the plant for vacation and installation of new equipment in period 4. After installation, the cost per unit will remain the same, but the output rate for regular time will be 450. Regular output is the same as in Example 1 for

periods 1, 2, and 3; 0 for period 4; and 450 for each of the remaining periods. Note, though, that the forecast of 400 units in period 4 must be dealt with. Prepare the aggregate plan, and compute its total cost.

2. Refer to Example 1. Suppose that the regular output rate will drop to 290 units per period due to an expected change in production requirements. Costs will not change. Prepare an aggregate plan and compute its total cost for each of these alternatives:
   a. Use overtime at a fixed rate of 20 units per period as needed. Plan for an ending inventory of zero for period 6. Backlogs cannot exceed 90 units per period.
   b. Use subcontracting at a maximum rate of 50 units per period; the usage need not be the same in every period. Have an ending inventory of zero in the last period. Again backlogs cannot exceed 90 units in any period. Compare these two plans.
3. Refer to Example 2. Suppose you can use a combination of overtime and subcontracting, but you cannot use subcontracting in more than two periods. Up to 50 units of subcontracting and either 0 or 40 units of overtime are allowed per period. Subcontracting is $6 per unit, and overtime is $3 per unit. (Hint: Use subcontracting only when overtime units are not sufficient to decrease backlogs to 80 units or less.) Plan for an ending inventory balance of 0 for period 6. Prepare a plan that will minimize total cost.
4. Refer to Example 2. Determine whether a plan to use subcontracting at a maximum rate of 50 units per period as needed with no overtime would achieve a lower total cost than the plan shown in Example 2. Again, plan for a zero inventory balance at the end of period 6.
5. Manager T. C. Downs of Plum Engines, a producer of lawn mowers and leaf blowers, must develop an aggregate plan given the forecast for engine demand shown in the table. The department has a normal capacity of 130 engines per month. Normal output has a cost of $60 per engine. The beginning inventory is zero engines. Overtime has a cost of $90 per engine.
   a. Develop a chase plan that matches the forecast and compute the total cost of your plan.
   b. Compare the costs to a level plan that uses inventory to absorb fluctuations. Inventory carrying cost is $2 per engine per month. Backlog cost is $90 per engine per month.

Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Total**
Forecast	120	135	140	120	125	125	140	135	1,040

6. Manager Chris Channing of Fabric Mills, Inc., has developed the forecast shown in the table for bolts of cloth. The figures are in hundreds of bolts. The department has a normal capacity of 275(00) bolts per month, except for the seventh month, when capacity will be 250(00) bolts. Normal output has a cost of $40 per hundred bolts. Workers can be assigned to other jobs if production is less than normal. The beginning inventory is zero bolts.
   a. Develop a chase plan that matches the forecast and compute the total cost of your plan. Overtime is $60 per hundred bolts.
   b. Would the total cost be less with regular production with no overtime, but using a subcontractor to handle the excess above normal capacity at a cost of $50 per hundred bolts? Backlogs are not allowed. The inventory carrying cost is $2 per hundred bolts.

Month	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Total**
Forecast	250	300	250	300	280	275	270	1,925

7. SummerFun, Inc., produces a variety of recreation and leisure products. The production manager has developed an aggregate forecast:

Month	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Total**
Forecast	50	44	55	60	50	40	51	350

Use the following information to develop aggregate plans.

Regular production cost	$80 per unit	Back-order cost	$20 per unit
Overtime production cost	$120 per unit	Beginning inventory	0 units
Regular capacity	40 units per month		
Overtime capacity	8 units per month		
Subcontracting cost	$140 per unit		
Subcontracting capacity	12 units per month		
Holding cost	$10 per unit per month		

Develop an aggregate plan using each of the following guidelines and compute the total cost for each plan. Which plan has the lowest total cost?

a. Use regular production. Supplement using inventory, overtime, and subcontracting as needed. No backlogs allowed.

b. Use a level strategy. Use a combination of backlogs, subcontracting, and inventory to handle variations in demand.

8. Nowjuice, Inc., produces bottled pickle juice. A planner has developed an aggregate forecast for demand (in cases) for the next six months.

Month	May	Jun	Jul	Aug	Sep	Oct
Forecast	4,000	4,800	5,600	7,200	6,400	5,000

Use the following information to develop aggregate plans.

Regular production cost	$10 per case
Regular production capacity	5,000 cases
Overtime production cost	$16 per case
Subcontracting cost	$20 per case
Holding cost	$1 per case per month
Beginning inventory	0

Develop an aggregate plan using each of the following guidelines and compute the total cost for each plan. Which plan has the lowest total cost?

a. Use level production. Supplement using overtime as needed.

b. Use a combination of overtime (500 cases per period maximum), inventory, and subcontracting (500 cases per period maximum) to handle variations in demand.

c. Use overtime up to 750 cases per period and inventory to handle variations in demand.

9. Wormwood, Ltd., produces a variety of furniture products. The planning committee wants to prepare an aggregate plan for the next six months using the following information:

	MONTH					
	1	2	3	4	5	6
Demand	160	150	160	180	170	140
Capacity						
Regular	150	150	150	150	160	160
Overtime	10	10	0	10	10	10

Cost Per Unit	
Regular time	$50
Overtime	$75
Subcontract	$80
Inventory, per period	$ 4

Subcontracting can handle a maximum of 10 units per month. Beginning inventory is zero. Develop a plan that minimizes total cost. No back orders are allowed.

10. Refer to Solved Problem 1. Prepare two additional aggregate plans. Call the one in the solved problem plan A. For plan B, hire one more worker at a cost of $200. Make up any shortfall using subcontracting at $8 per unit, with a maximum of 20 units per period (i.e., use subcontracting to reduce back orders when the forecast exceeds regular output). Note that the ending inventory in period 9 should be zero. Therefore, Total forecast − Total output = Quantity subcontracted. An additional constraint is that back orders cannot exceed 80 units in any period. For plan C, assume no workers are hired (so regular output is 200 units per period instead of 210 as in plan B). Use subcontracting as needed, but no more than 20 units per period. Compute the total cost of each plan. Which plan has the lowest cost?

11. Refer to Solved Problem 1. Suppose another option is to use part-time workers to assist during seasonal peaks. The cost per unit, including hiring and training, is $11. The output rate is 10 units per worker per period for all workers. A maximum of 10 part-time workers can be used, and the same

number of part-time workers must be used in all periods that have part-time workers. The ending inventory in period 9 should be 10 units. The limit on backlogs is 20 units per period. Try to make up backlogs as soon as possible. Compute the total cost for this plan, and compare it to the cost of the plan used in the solved problem. Assume 20 full-time workers.

12. Refer to Solved Problem 1. Prepare an aggregate plan that uses overtime ($9 per unit, maximum output 25 units per period) and inventory variation. Try to minimize backlogs. The ending inventory in period 9 should be zero, and the limit on backlogs is 60 units per period. Note that Total output = Total regular output + Overtime quantity. Compute the total cost of your plan, and compare it to the total cost of the plan used in the solved problem. Assume 20 full-time workers.
13. Refer to Solved Problem 1. Prepare an aggregate plan that uses some combination of laying off ($100 per worker), subcontracting ($8 per unit, maximum of 20 units per period, must use for three consecutive periods), and overtime ($9 per unit, maximum of 25 per period, maximum of 60 for the planning horizon). Compute the total cost, and compare it with any of the other plans you have developed. Which plan has the lowest total cost? Assume you start with 21 workers.
14. Verify the transportation solution shown in Example 3.
15. Refer to Example 3. Suppose that an increase in warehousing costs and other costs brings inventory carrying costs to $2 per unit per month. All other costs and quantities remain the same. Determine a revised solution to this transportation problem.
16. Refer to Example 3. Suppose that regular-time capacity will be reduced to 440 units in period 3 to accommodate a companywide safety inspection of equipment. What will the additional cost of the optimal plan be as compared to the one shown in Example 3? Assume all costs and quantities are the same as given in Example 3 except for the regular-time output in period 3.
17. Solve Problem 16 using an inventory carrying cost of $2 per unit per period.
18. Dundas Bike Components Inc. of Wheelville, Illinois, manufactures bicycle wheels in two different sizes for the Big Bike Co. assembly plant located across town. David Dundas, the firm's owner-manager, has just received Big Bike's order for the next six months.

	20-Inch Wheels	24-Inch Wheels
Nov.	1,000 units	500 units
Dec.	900	500
Jan.	600	300
Feb.	700	500
Mar.	1,100	400
Apr.	1,100	600

a. Under what circumstances will it be possible for David to develop just one aggregate plan rather than two (one for each size wheel)? Explain in two to three sentences without calculations.

b. Currently Dundas employs 28 full-time, highly skilled employees, each of whom can produce 50 wheels per month. Because skilled labor is in short supply in the Wheelville area, David would like to develop a pure level-output plan. There is no inventory of finished wheels on hand at present, but David would like to have 300 on hand at the end of April. Big Bike will tolerate back orders of up to 200 units per month. Show your level plan in tabular form.

c. Calculate the total annual cost of your plan using these costs:

Regular	$5.00	Hiring	$300
Overtime	$7.50	Layoff	$400
Part-time	NA	Inventory	$1.00
Subcontract	NA	Backorder	$6.00

19. Prepare a master production schedule for industrial pumps in the manner of Figure 12.10 in the chapter. Use the same inputs as the example, but change the MPS rule from "schedule production when the projected on-hand inventory would be negative without production" to "schedule production when the projected on-hand inventory would be less than 10 without production."
20. Update the master schedule shown in Figure 12.10 given these updated inputs: It is now the end of week 1; customer orders are 25 for week 2, 16 for week 3, 11 for week 4, 8 for week 5, and 3 for week 6. Use the MPS rule of ordering production when projected on-hand inventory would be negative without production.

21. Prepare a master schedule like that shown in Figure 12.10 given this information: The forecast for each week of an eight-week schedule is 50 units. The MPS rule is to schedule production if the projected on-hand inventory would be negative without it. Customer orders (committed) are

Week	Customer Orders
1	52
2	35
3	20
4	12

Use a production lot size of 75 units and no beginning inventory.

22. Determine the available-to-promise (ATP) quantities for each period for Problem 21.
23. Prepare a schedule like that shown in Figure 12.11 for the following situation: The forecast is 80 units for each of the first two periods and 60 units for each of the next three periods. The starting inventory is 20 units. The company uses a chase strategy for determining the production lot size, except there is an upper limit on the lot size of 70 units. Also, the desired safety stock is 10 units. Note: The ATP quantities are based on maximum allowable production and do not include safety stock. Committed orders are

Period	Customer Orders
1	82
2	80
3	60
4	40
5	20

Eight Glasses a Day (EGAD) — CASE

The EGAD Bottling Company has recently expanded its bottled spring water operations to include several new flavors. Marketing manager Georgianna Mercer is predicting an upturn in demand based on the new offerings and the increased public awareness of the health benefits of drinking more water. She has prepared aggregate forecasts for the next six months, as shown in the following table (quantities are in tankloads):

Month	May	Jun	Jul	Aug	Sept	Oct	Total
Forecast	50	60	70	90	80	70	420

Production manager Mark Mercer (no relation to Georgianna) has developed the following information. (Note that one unit equals 100 bottles, and there are 10,000 bottles per tankload.)

Regular production cost	$10 per unit
Regular production capacity	60 units
Overtime production cost	$16 per unit
Subcontracting cost	$18 per unit
Holding cost	$2 per unit per month
Back-ordering cost	$50 per month per unit
Beginning inventory	0 units

Among the strategies being considered are

1. Level production supplemented by up to 10 tankloads a month from overtime.
2. A combination of overtime, inventory, and subcontracting.
3. Using overtime for up to 15 tankloads a month, along with inventory to handle variations.

The objective is to choose the plan that has the lowest cost. Which plan would you recommend?

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CHAPTER 13

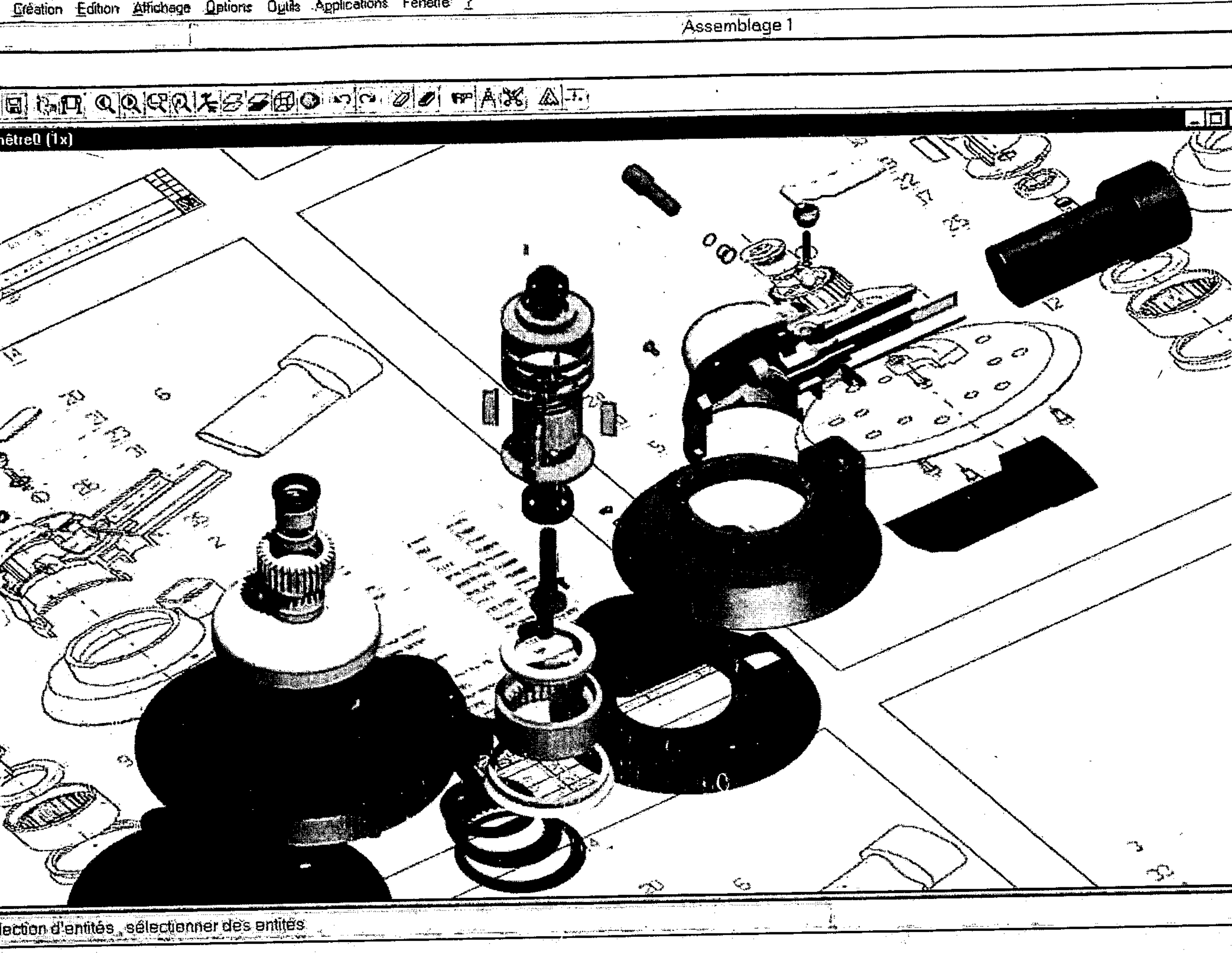
MRP and ERP

LEARNING OBJECTIVES

After completing this chapter, you should be able to:

1. Describe the conditions under which MRP is most appropriate.
2. Describe the inputs, outputs, and nature of MRP processing.
3. Explain how requirements in a master production schedule are translated into material requirements for lower-level items.
4. Discuss the benefits and requirements of MRP.
5. Explain how an MRP system is useful in capacity requirements planning.
6. Outline the potential benefits and some of the difficulties users have encountered with MRP.
7. Describe MRP II and its benefits.
8. Describe ERP, what it provides, and its hidden costs.

CHAPTER OUTLINE



This chapter describes MRP (material requirements planning), MRP II (manufacturing resource planning), and ERP (enterprise resource planning). MRP is a planning and scheduling technique used for batch production of assembled items. The first portion of the chapter is devoted to MRP. The remainder of the chapter is devoted to MRP II and ERP, which involve the use of extensive software to integrate record keeping and information sharing throughout an organization.

MRP

The raw materials, purchased parts, and other components of assembled items are subject to what is called *dependent demand*, which requires an approach different from the inventory management techniques described in the chapter on inventory management.

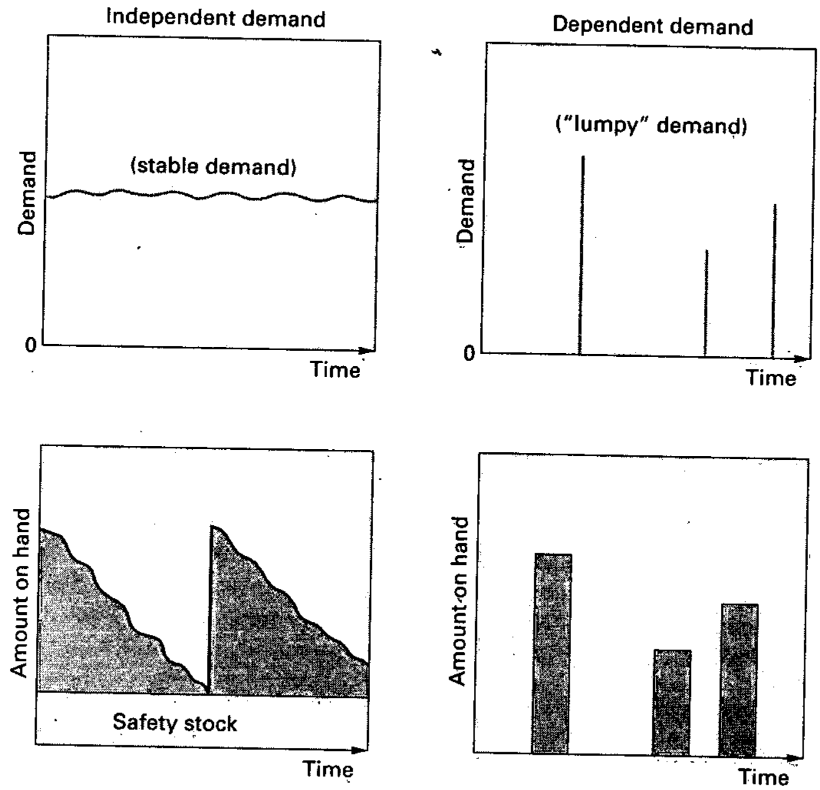
Dependent versus Independent Demand

A major distinction in the way inventories are managed results from the nature of demand for those items. When demand for items is derived from plans to make certain products, as it is with raw materials, parts, and assemblies used in producing a finished product, those items are said to have **dependent demand.** The parts and materials that go into the production of an automobile are examples of dependent demand because the total quantity of parts and raw materials needed during any time period is a function of the number of cars that will be produced. Conversely, demand for the *finished* cars is independent—a car is not a component of another item.

dependent demand Demand for items that are subassemblies or component parts to be used in the production of finished goods.

FIGURE 13.1

Comparison of independent and dependent demand



Independent demand is fairly stable once allowances are made for seasonal variations, but dependent demand tends to be sporadic or "lumpy"; large quantities are used at specific points in time with little or no usage at other times. For example, a firm that produces lawn and garden equipment might make a variety of items, such as trimmers, lawn mowers, and small tractors. Suppose that the various products are produced periodically—in one month, push mowers; in the next month, mulching mowers; and in the third month, tractors. Some components may be used in most of the items (e.g., nuts and bolts, screws). It makes sense to have a continual inventory of these parts because they are always needed. On the other hand, some parts might be used for only one item. Consequently, demand for those parts occurs only when that item is being produced, which might be once every eight or nine weeks; the rest of the time, demand is zero. Thus, demand is "lumpy." Lumpy demand also can be the result of customer ordering rules (e.g., EOQ ordering). Because of these tendencies, independent-demand items must be carried on a continual basis, but dependent-demand items need only be stocked just prior to the time they will be needed in the production process. Moreover, the predictability of usage of dependent-demand items means that there is little or no need for safety stock. Figure 13.1 illustrates key differences in independent- and dependent-demand inventories.

AN OVERVIEW OF MRP

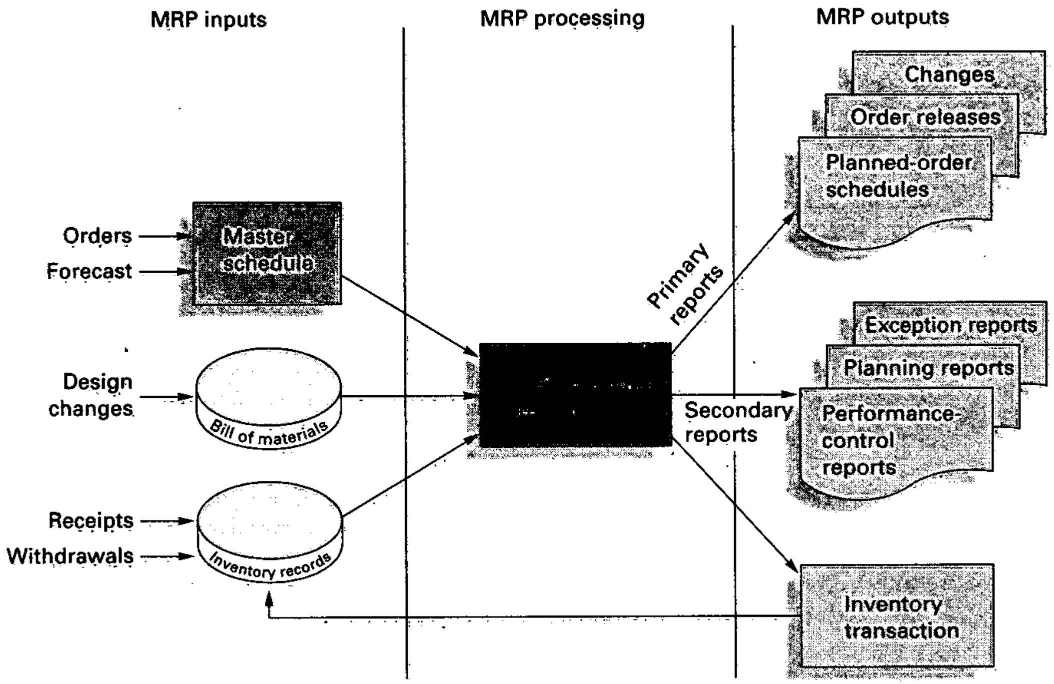
material requirements planning Computer-based information system that translates master schedule requirements for end items into time-phased requirements for subassemblies, components, and raw materials.

Material requirements planning (MRP) is a computer-based information system that translates the finished product requirements of the master schedule into time-phased requirements for subassemblies, component parts, and raw materials, working backward from the due date using lead times and other information to determine when and how much to order. Hence, requirements for end items generate requirements for lower-level components, which are broken down by planning periods (e.g., weeks) so that ordering, fabrication, and assembly can be scheduled for timely completion of end items while inventory levels are kept reasonably low.

Material requirements planning is as much a philosophy as it is a technique, and as much an approach to scheduling as it is to inventory control.

FIGURE 13.2

Overview of MRP



Historically, ordering and scheduling of assembled products suffered from two difficulties. One was the enormous task of setting up schedules, keeping track of large numbers of parts and components, and coping with schedule and order changes. The other was a lack of differentiation between independent demand and dependent demand. All too often, techniques designed for independent-demand items were used to handle assembled items, which resulted in excessive inventories. Consequently, inventory planning and scheduling presented major problems for manufacturers before the development of MRP.

MRP begins with a schedule for finished goods that is converted into a schedule of requirements for the subassemblies, component parts, and raw materials needed to produce the finished items in the specified time frame. Thus, MRP is designed to answer three questions: *what* is needed? *how much* is needed? and *when* is it needed?

The primary inputs of MRP are a bill of materials, which tells the composition of a finished product; a master schedule, which tells how much finished product is desired and when; and an inventory records file, which tells how much inventory is on hand or on order. The planner processes this information to determine the *net* requirements for each period of the planning horizon.

Outputs from the process include planned-order schedules, order releases, changes, performance-control reports, planning reports, and exception reports. These topics are discussed in more detail in subsequent sections. Figure 13.2 provides an overview of an MRP system.

MRP INPUTS

An MRP system has three major sources of information: a master schedule, a bill-of-materials file, and an inventory records file (see Figure 13.2). Let's consider each of these inputs.

The Master Schedule

The **master schedule,** also referred to as the *master production schedule,* states which end items are to be produced, when they are needed, and in what quantities. Figure 13.3 illustrates

master schedule One of three primary inputs in MRP; states which end items are to be produced, when these are needed, and in what quantities.

FIGURE 13.3

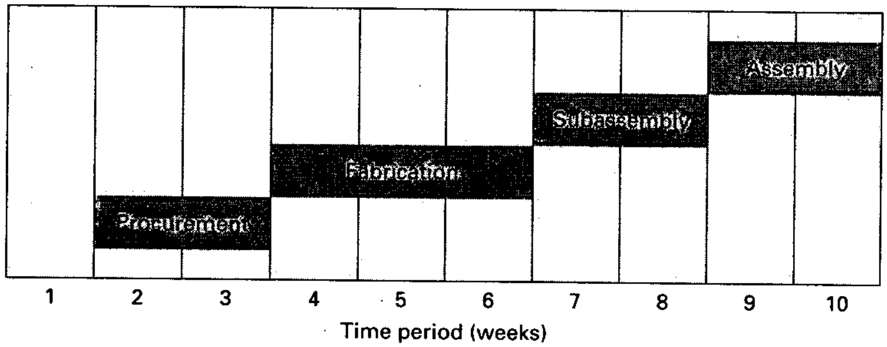
A master schedule for end item X

Week number

Item: X	1	2	3	4	5	6	7	8
Quantity				100				150

FIGURE 13.4

The planning horizon must cover the cumulative lead time



a portion of a master schedule that shows planned output for end item X for the planning horizon. The schedule indicates that 100 units of X will be needed (e.g., for shipments to customers) at the *start* of week 4 and that another 150 units will be needed at the *start* of week 8.

The quantities in a master schedule come from a number of different sources, including customer orders, forecasts, and orders from warehouses to build up seasonal inventories.

The master schedule separates the planning horizon into a series of time periods or time *buckets,* which are often expressed in weeks. However, the time buckets need not be of equal length. In fact, the near-term portion of a master schedule may be in weeks, but later portions may be in months or quarters. Usually, plans for those more distant time periods are more tentative than near-term requirements.

cumulative lead time The sum of the lead times that sequential phases of a process require, from ordering of parts or raw materials to completion of final assembly.

Although a master production schedule has no set time period that it must cover, most managers like to plan far enough into the future so they have some general idea of probable upcoming demands for the near term. It is important, though, that the master schedule cover the *stacked* or **cumulative lead time** necessary to produce the end items. This amounts to the sum of the lead times that sequential phases of the production or assembly process require, as illustrated in Figure 13.4, where a total of nine weeks of lead time is needed from ordering parts and raw materials until final assembly is completed.

The Bill of Materials

bill of materials (BOM) One of the three primary inputs of MRP; a listing of all of the raw materials, parts, subassemblies, and assemblies needed to produce one unit of a product.

product structure tree Visual depiction of the requirements in a bill of materials, where all components are listed by levels.

A **bill of materials (BOM)** contains a listing of all of the assemblies, subassemblies, parts, and raw materials that are needed to produce *one* unit of a finished product. Thus, each finished product has its own bill of materials.

The listing in the bill of materials is hierarchical; it shows the quantity of each item needed to complete one unit of the following level of assembly. The nature of this aspect of a bill of materials is clear when you consider a **product structure tree,** which provides a visual depiction of the subassemblies and components needed to assemble a product. Figure 13.5 shows an *assembly diagram* for a chair and a product structure tree for the chair. This chart is a simple product structure tree for a chair. The end item (in this case, the chair, the finished product) is shown at the top of the tree. Just beneath it are the subassemblies, or major components, that must be put together to make up the end item. Beneath each major component are the necessary lesser components. At each stage moving down the tree are the components (parts, materials) needed to make one unit of the next higher item in the tree.

A product structure tree is useful in illustrating how the bill of materials is used to determine the quantities of each of the ingredients (requirements) needed to obtain a desired number of end items.

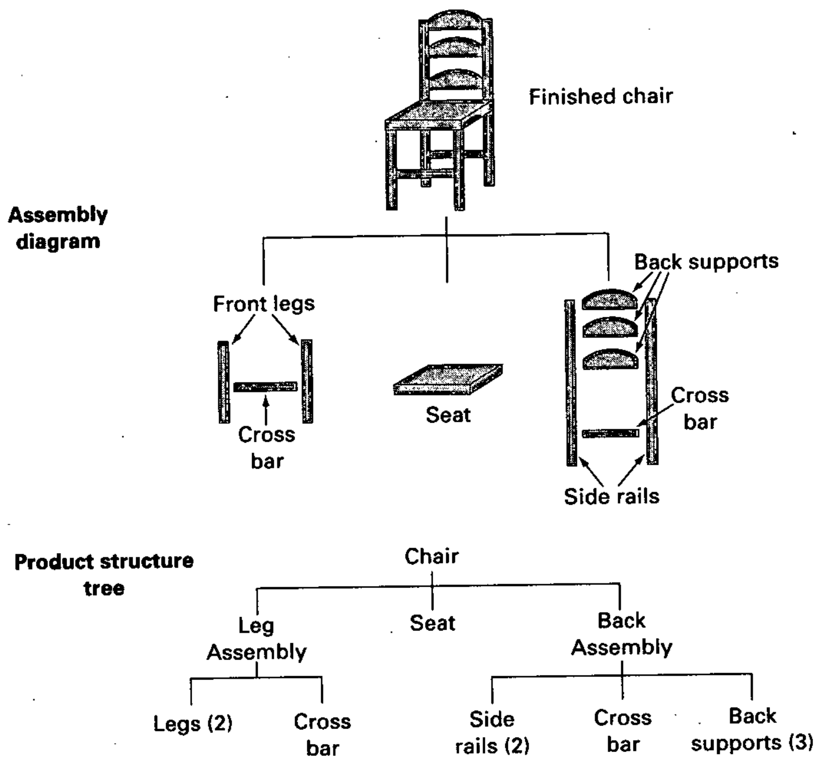


FIGURE 13.5

Assembly diagram and product structure tree for chair assembly

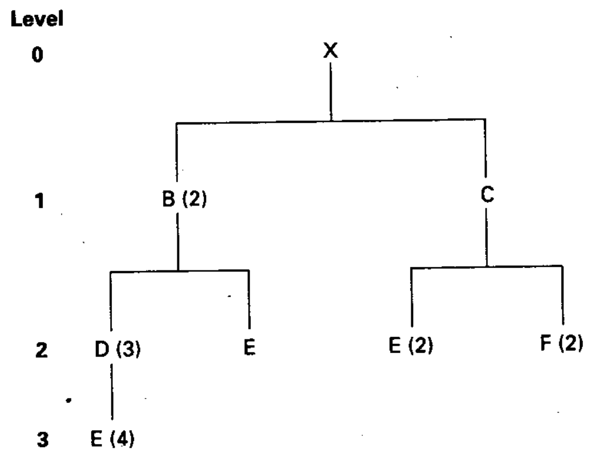


FIGURE 13.6

A product structure tree for end item X

Let's consider the product structure tree shown in Figure 13.6. End item X is composed of two Bs and one C. Moreover, each B requires three Ds and one E, and each D requires four Es. Similarly, each C is made up of two Es and two Fs. These *requirements* are listed by *level,* beginning with 0 for the end item, then 1 for the next level, and so on. The items at each level are *components* of the next level up and, as in a family tree, are *parents* of their respective components. Note that the quantities of each item in the product structure tree refer only to the amounts needed to complete the assembly at the next higher level.

EXAMPLE 1

Use the information presented in Figure 13.6 to do the following:

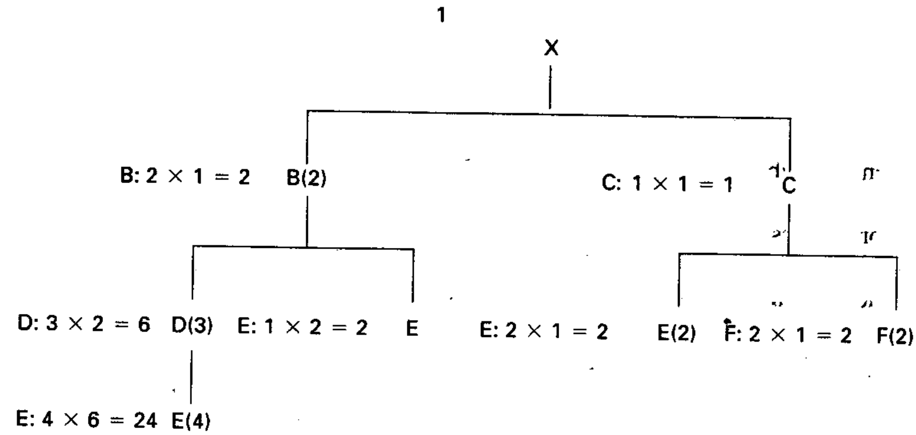
a. Determine the quantities of B, C, D, E, and F needed to assemble one X.

b. Determine the quantities of these components that will be required to assemble 10 Xs, taking into account the quantities on hand (i.e., in inventory) of various components:

Component	On Hand
B	4
C	10
D	8
E	60

SOLUTION

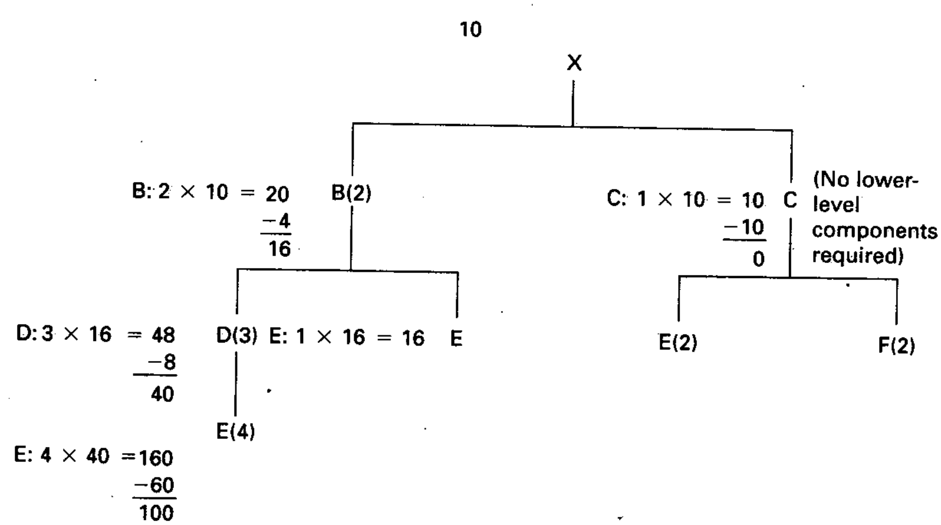
a.



Thus, one X will require

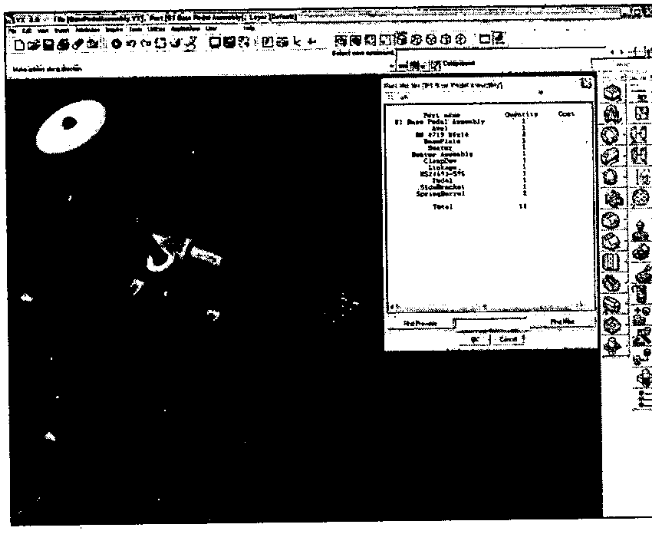
B:	2
C:	1
D:	6
E:	28 (Note that E occurs in three places, with requirements of 24 + 2 + 2 = 28)
F:	2

b.



Thus, given the amounts of on-hand inventory, 10 Xs will require

B:	16
C:	0
D:	40
E:	116
F:	0



VX Corporation's CAD CAM software can be used not only for design specification, but also to prepare parts lists. This screen shows a parts lists for a bass drum pedal along with a three-dimensional view of the product subassemblies.

www.vx.com

Determining total requirements is usually more complicated than Example 1 might suggest. For one thing, many products have considerably more components. For another, the issue of *timing* is essential (i.e., when must the components be ordered or made) and must be included in the analysis. Finally, for a variety of reasons, some of the components/ subassemblies may be on hand (i.e., currently in inventory). Consequently, in determining total requirements, the amounts on hand must be *netted out* (i.e., subtracted from the apparent requirements) to determine the true requirements as illustrated in Example 1.

Comment. It is extremely important that the bill of materials accurately reflect the composition of a product, particularly since errors at one level become magnified by the multiplication process used to determine quantity requirements. As obvious as this might seem, many companies find themselves with incorrect bills-of-material records. These make it impossible to effectively determine material requirements; moreover, the task of correcting these records can be complex and time-consuming. Accurate records are a prerequisite for effective MRP.

The Inventory Records

Inventory records refer to stored information on the status of each item by time period, called *time buckets.* This includes gross requirements, scheduled receipts, and expected amount on hand. It also includes other details for each item, such as supplier, lead time, and lot size policy. Changes due to stock receipts and withdrawals, canceled orders, and similar events also are recorded in this file.

inventory records One of the three primary inputs in MRP; includes information on the status of each item by time period.

Like the bill of materials, inventory records must be accurate. Erroneous information on requirements or lead times can have a detrimental impact on MRP and create turmoil when incorrect quantities are on hand or expected delivery times are not met.

MRP PROCESSING

MRP processing takes the end item requirements specified by the master schedule and "explodes" them into *time-phased* requirements for assemblies, parts, and raw materials using the bill of materials offset by lead times. You can see the time-phasing of requirements in the assembly time chart in Figure 13.7. For example, raw materials D, F, and I must be ordered at the start of week 2; part C at the start of week 4; and part H at the start of week 5 in order to be available for delivery as planned.

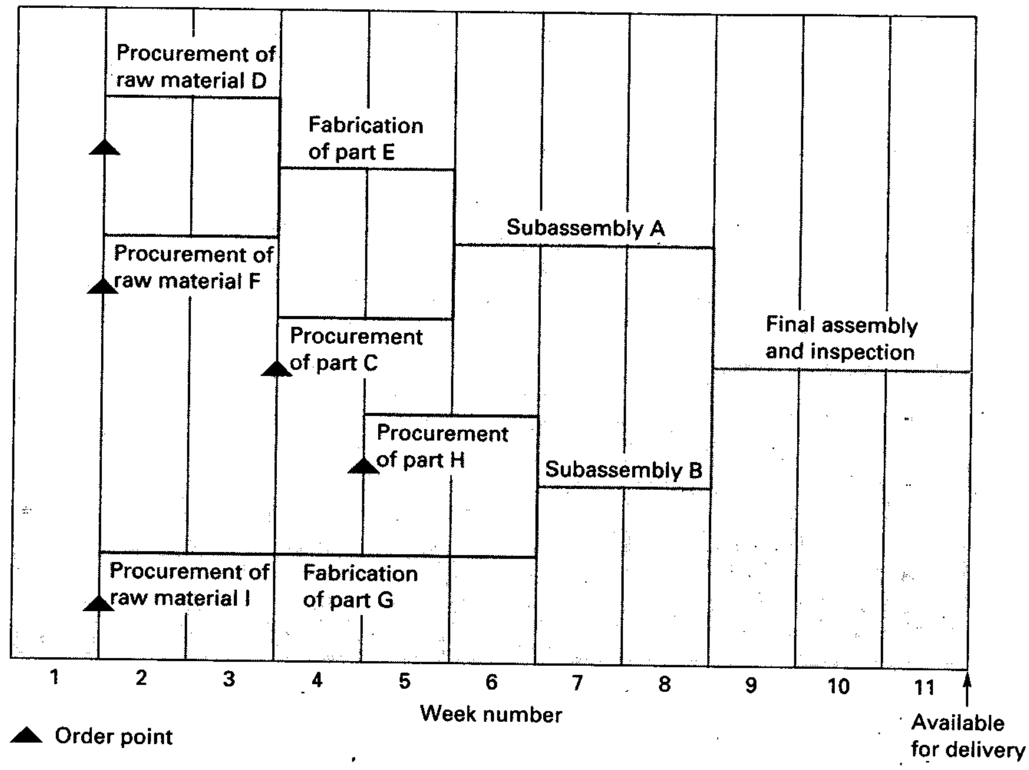
The quantities that are generated by exploding the bill of materials are *gross requirements;* they do not take into account any inventory that is currently on hand or due to be received. The materials that a firm must actually acquire to meet the demand generated by the master schedule are the *net material requirements.*

The determination of the net requirements (*netting*) is the core of MRP processing. One accomplishes it by subtracting from gross requirements the sum of inventory on hand and any scheduled receipts, and then adding in safety stock requirements, if applicable:

$$\begin{array}{c}\text{Net}\\ \text{requirements}\\ \text{in period } t\end{array} = \begin{array}{c}\text{Gross}\\ \text{requirements}\\ \text{in period } t\end{array} - \begin{array}{c}\text{Projected}\\ \text{inventory}\\ \text{in period } t\end{array} + \begin{array}{c}\text{Safety}\\ \text{stock}\end{array} \qquad (13\text{–}1)$$

FIGURE 13.7

Assembly time chart showing material order points needed to meet scheduled availability of the end item



For simplicity, we will omit safety stock from computations in examples and most problems. Net requirements are sometimes adjusted to include an allowance for waste; but for simplicity, this, too, we will not include in examples or most problems.

gross requirements Total expected demand for an item or raw material in a time period.

scheduled receipts Open orders scheduled to arrive from vendors or elsewhere in the pipeline.

projected on hand Expected amount of inventory that will be on hand at the beginning of each time period.

net requirements The actual amount needed in each time period.

planned-order receipts Quantity expected to be received by the beginning of the period in which it is shown.

planned-order releases Planned amount to order in each time period; planned-order receipts offset by lead time.

The timing and sizes of orders (i.e., materials ordered from suppliers or work started within the firm) are determined by *planned-order releases.* The timing of the receipts of these quantities is indicated by *planned-order receipts.* Depending on ordering policy, the planned-order releases may be multiples of a specified quantity (e.g., 50 units), or they may be equal to the quantity needed at that time. Although there are other possibilities, these two seem to be the most widely used. Example 2 illustrates the difference between these two ordering policies as well as the general concepts of time-phasing material requirements in MRP. As you work through the example, you may find the following list of terms helpful.

Gross requirements: The total expected demand for an item or raw material *during* each time period without regard to the amount on hand. For end items, these quantities are shown in the master schedule; for components, these quantities are derived from the planned-order releases of their immediate "parents."

Scheduled receipts: Open orders (orders that have been placed and are) scheduled to arrive from vendors or elsewhere in the pipeline by the *beginning* of a period.

Projected on hand: The expected amount of inventory that will be on hand at the *beginning* of each time period: scheduled receipts plus available inventory from last period.

Net requirements: The actual amount needed in each time period.

Planned-order receipts: The quantity expected to be received by the *beginning* of the period in which it is shown. Under lot-for-lot ordering, this quantity will equal net requirements. Under lot-size ordering, this quantity may exceed net requirements. Any excess is added to available inventory in the *next* time period for simplicity, although in reality, it would be available in that period.

Planned-order releases: Indicates a *planned* amount to order in each time period; equals planned-order receipts offset by lead time. This amount generates gross requirements at the next level in the assembly or production chain. When an order is executed, it is removed from "planned-order releases" and entered under "scheduled receipts."

These quantities are used in a time-phased plan in the following format. The column for week 0 is used to show beginning inventory.

Week Number	0	1	2	3	4	5	6	7	8
Item:									
Gross requirements									
Scheduled receipts									
Projected on hand									
Net requirements									
Planned-order receipts									
Planned-order releases									

EXAMPLE 2

A firm that produces wood shutters and bookcases has received two orders for shutters: one for 100 shutters and one for 150 shutters. The 100-unit order is due for delivery at the start of week 4 of the current schedule, and the 150-unit order is due for delivery at the start of week 8. Each shutter consists of two frames and four slatted wood sections. The wood sections are made by the firm, and fabrication takes one week. The frames are ordered, and lead time is two weeks. Assembly of the shutters requires one week. There is a scheduled receipt of 70 wood sections in (i.e., at the beginning of) week 1. Determine the size and timing of planned-order releases necessary to meet delivery requirements under each of these conditions:

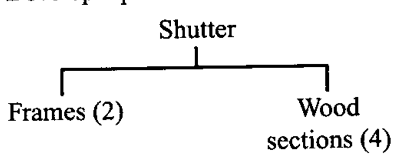
1. Lot-for-lot ordering (i.e., order size equal to net requirements).
2. Lot-size ordering with a lot size of 320 units for frames and 70 units for wood sections.

SOLUTION

a. Develop a master schedule:

Week number	1	2	3	4	5	6	6	8
Quantity				100				150

b. Develop a product structure tree:



c. Using the master schedule, determine gross requirements for shutters. Next, compute net requirements. Using *lot-for-lot ordering,* determine planned-order receipt quantities and the planned-order release timing to satisfy the master schedule (see Figure 13.8).

The master schedule calls for 100 shutters to be ready for delivery, and no shutters are projected to be on hand at the start of week 4, so the net requirements are also 100 shutters. Therefore, planned receipts for week 4 equal 100 shutters. Because shutter assembly requires one week, this means a planned-order release at the start of week 3. Using the same logic, 150 shutters must be assembled during week 7 in order to be available for delivery at the start of week 8.

The planned-order release of 100 shutters at the start of week 3 means that 200 frames (gross requirements) must be available at that time. Because none are expected to be on hand, this generates net requirements of 200 frames and necessitates planned receipts of 200 frames by the start of week 3. With a two-week lead time, this means that the firm must order 200 frames at the start of week 1. Similarly, the planned-order release of 150 shutters at week 7 generates gross and net requirements of 300 frames for week 7 as well

FIGURE 13.8

MRP schedule with lot-for-lot ordering

Master schedule for shutters:

Week number	Beg. Inv.	1	2	3	4	5	6	7	8
Quantity					100				150

Shutters: LT = 1 week	Beg. Inv.	1	2	3	4	5	6	7	8
Gross requirements					100				150
Scheduled receipts									
Projected on hand									
Net requirements					100				150
Planned-order receipts					100				150
Planned-order releases				100				150	

times 2   times 2

Frames: LT = 2 weeks	Beg. Inv.	1	2	3	4	5	6	7	8
Gross requirements				200				300	
Scheduled receipts									
Projected on hand									
Net requirements				200				300	
Planned-order receipts				200				300	
Planned-order releases		200				300			

times 4   times 4

Wood sections: LT = 1 week	Beg. Inv.	1	2	3	4	5	6	7	8
Gross requirements				400				600	
Scheduled receipts		70							
Projected on hand		70	70	70					
Net requirements				330				600	
Planned-order receipts				330				600	
Planned-order releases			330				600		

as planned receipts for that time. The two-week lead time means the firm must order frames at the start of week 5.

The planned-order release of 100 shutters at the start of week 3 also generates gross requirements of 400 wood sections at that time. However, because 70 wood sections are expected to be on hand, net requirements are $400 - 70 = 330$. This means a planned receipt of 330 by the start of week 3. Since fabrication time is one week, the fabrication must start (planned-order release) at the beginning of week 2.

Similarly, the planned-order release of 150 shutters in week 7 generates gross requirements of 600 wood sections at that point. Because no on-hand inventory of wood sections is projected, net requirements are also 600, and planned-order receipt is 600 units. Again, the one-week lead time means 600 sections are scheduled for fabrication at the start of week 6.

d. Under lot-size ordering, the only difference is the possibility that planned receipts will exceed net requirements. The excess is recorded as projected inventory in the following period. For example, in Figure 13.9, the order size for frames is 320 units. Net requirements for week 3 are 200; thus, there is an excess of $320 - 200 = 120$ units, which become projected inventory in the next week. Similarly, net frame requirements of 180 units are 140

FIGURE 13.9

MRP schedule with lot sizes for components

Master schedule for shutters:

Week number	Beg. Inv.	1	2	3	4	5	6	7	8
Quantity					100				150

Shutters: LT = 1 week; Lot size = lot-for-lot

	Beg. Inv.	1	2	3	4	5	6	7	8
Gross requirements					100				150
Scheduled receipts									
Projected on hand									
Net requirements					100				150
Planned-order receipts					100				150
Planned-order releases				100				150	

times 2 times 2

Frames: LT = 2 weeks; Lot size = multiples of 320

	Beg. Inv.	1	2	3	4	5	6	7	8
Gross requirements				200				300	
Scheduled receipts									
Projected on hand					120	120	120	120	140
Net requirements				200				180	
Planned-order receipts				320				320	
Planned-order releases		320				320			

times 4 times 4

Wood sections: LT = 1 week; Lot size = multiples of 70

	Beg. Inv.	1	2	3	4	5	6	7	8
Gross requirements				400				600	
Scheduled receipts		70							
Projected on hand		70	70	70	20	20	20	20	50
Net requirements				330				580	
Planned-order receipts				350				630	
Planned-order releases			350				630		

less than the 320 order size; again, the excess becomes projected inventory in week 8. The same thing happens with wood sections; an excess of planned receipts in weeks 3 and 7 is added to projected inventory in weeks 4 and 8. Note that the order size must be in *multiples* of the lot size; for week 3 it is 5 times 70, and for week 7 it is 9 times 70.

MRP provides plans for the end item and each of its subassemblies and components. Conceptually, this amounts to what is depicted in Figure 13.10. Practically speaking, however, the number of components in even a relatively simple product would make the width of the resulting spreadsheet far too wide to handle. Consequently, the plans for the individual components are *stacked,* as illustrated in the preceding example. Because of this, it is important to refer to the product tree in order to track relationships between components.

Example 2 is useful for describing some of the main features of MRP processing, but it understates the enormity of the task of keeping track of material requirements, especially in situations where the same subassemblies, parts, or raw materials are used in a number of different products. Differences in timing of demands and quantities needed, revisions caused by late deliveries, high scrap rates, and canceled orders, all have an impact on processing.

FIGURE 13.10

Net requirements at each level determine gross requirements at the next

Master schedule for shutters:

Week number	Beg. Inv.	1	2	3	4	5	6	7	8
Quantity									

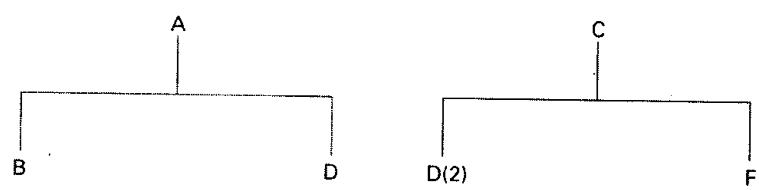
Item: Shutters									
Gross requirements									
Scheduled receipts									
Projected on hand									
Net requirements									
Planned-order receipts									
Planned-order releases									

Item: Frames								
Gross requirements								
Scheduled receipts								
Projected on hand								
Net requirements								
Planned-order receipts								
Planned-order releases								

Item: Wood sections								
Gross requirements								
Scheduled receipts								
Projected on hand								
Net requirements								
Planned-order receipts								
Planned-order releases								

FIGURE 13.11

Two different products have D as a component



Consider the two product structure trees shown in Figure 13.11. Note that both products have D as a component. Suppose we want to develop a material requirements plan for D given this additional information: There is a beginning inventory of 110 units of D on hand, and all items have lead times of one week. The master schedule calls for 80 units of A in Week 4 and 50 units of C in week 5. The plan is shown in Figure 13.12. Note that requirements for B and F are not shown because they are not related to (i.e., neither a "parent" nor a "child" of) D.

pegging The process of identifying the parent items that have generated a given set of material requirements for an item.

The term **pegging** denotes working this process in reverse; that is, identifying the parent items that have generated a given set of material requirements for some item such as D. Although the process may appear simple enough given the product trees and schedules shown in this chapter, when multiple products are involved, the process is more complex. Pegging enables managers to determine which product(s) will be affected if orders are late due to late deliveries, quality problems, or other problems.

FIGURE 13.12

Material requirements plan for component D

Master schedule

Week number		1	2	3	4	5	6
Quantity of A					80		
Quantity of C						50	

A LT = 1	Beg. Inv.	1	2	3	4	5	6
Gross requirements					80		
Scheduled receipts							
Projected on hand							
Net requirements					80		
Planned-order receipts					80		
Planned-order releases				(80)			

C LT = 1	Beg. Inv.	1	2	3	4	5	6
Gross requirements						50	
Scheduled receipts							
Projected on hand							
Net requirements						50	
Planned-order receipts						50	
Planned-order releases					(50)		

times 2

D LT = 1	Beg. Inv.	1	2	3	4	5	6
Gross requirements				80	100		
Scheduled receipts							
Projected on hand	110	110	110	110	30		
Net requirements					70		
Planned-order receipts					70		
Planned-order releases				70			

The importance of the computer becomes evident when you consider that a typical firm would have not one but many end items for which it needs to develop material requirements plans, each with its own set of components. Inventories on hand and on order, schedules, order releases, and so on, must all be updated as changes and rescheduling occur. Without the aid of a computer, the task would be almost hopeless; with the computer, planners can accomplish all of these things with much less difficulty.

Updating the System

A material requirements plan is not a static document. As time passes, some orders will have been completed, other orders will be nearing completion, and new orders will have been entered. In addition, there may have been changes to orders, such as changes in quantity, delays, missed deliveries of parts or raw materials, and so on. Hence, a material requirements plan is a "living" document, one that changes over time. And what we refer to as "Period 1" (i.e., the current period) is continually moving ahead; so what is now Period 2 will soon be Period 1. In a sense, schedules such as these have a *rolling horizon,* which means that plans are updated and revised so that they reflect the moving horizon over time.

regenerative system Approach that updates MRP records periodically.

net-change system Approach that updates MRP records continuously.

The two basic systems used to update MRP records are *regenerative* and *net change.* A **regenerative system** is updated periodically; a **net-change system** is continuously updated.

A regenerative system is essentially a batch-type system, which compiles all changes (e.g., new orders, receipts) that occur within the time interval (e.g., week) and periodically updates the system. Using that information, a revised production plan is developed in the same way that the original plan was developed (e.g., exploding the bill of materials, level by level).

In a net-change system, the production plan is modified to reflect changes as they occur. If some defective purchased parts had to be returned to a vendor, the manager can enter this information into the system as soon as it becomes known. Only the *changes* are exploded through the system, level by level; the entire plan would not be regenerated.

The regenerative system is best suited to fairly stable systems, whereas the net-change system is best suited to systems that have frequent changes. The obvious disadvantage of a regenerative system is the potential amount of lag between the time information becomes available and the time it can be incorporated into the material requirements plan. On the other hand, processing costs are typically less using regenerative systems; changes that occur in a given time period could ultimately cancel each other, thereby avoiding the need to modify and then remodify the plan. The disadvantages of the net-change system relate to the costs involved in continuously updating the system and the constant state of flux in a system caused by many small changes. One way around this is to enter minor changes periodically and major changes immediately. The primary advantage of the net-change system is that management can have up-to-date information for planning and control purposes.

MRP OUTPUTS

MRP systems have the ability to provide management with a fairly broad range of outputs. These are often classified as *primary reports,* which are the main reports, and *secondary reports,* which are optional outputs.

planned orders Schedule indicating the amount and timing of future orders.

order releases Authorization for the execution of planned orders.

changes Revisions of due dates or order quantities, or cancellations of orders.

Primary Reports Production and inventory planning and control are part of primary reports. These reports normally include the following:

1. **Planned orders,** a schedule indicating the amount and timing of future orders.
2. **Order releases,** authorizing the execution of planned orders.
3. **Changes** to planned orders, including revisions of due dates or order quantities and cancellations of orders.

performance-control reports Evaluation of system operation, including deviations from plans and cost information.

planning reports Data useful for assessing future material requirements.

exception reports Data on any major discrepancies encountered.

Secondary Reports Performance control, planning, and exceptions belong to secondary reports.

1. **Performance-control reports** evaluate system operation. They aid managers by measuring deviations from plans, including missed deliveries and stockouts, and by providing information that can be used to assess cost performance.
2. **Planning reports** are useful in forecasting future inventory requirements. They include purchase commitments and other data that can be used to assess future material requirements.
3. **Exception reports** call attention to major discrepancies such as late and overdue orders, excessive scrap rates, reporting errors, and requirements for nonexistent parts.

The wide range of outputs generally permits users to tailor MRP to their particular needs.

OTHER CONSIDERATIONS

Aside from the main details of inputs, outputs, and processing, managers must be knowledgeable about a number of other aspects of MRP. These include the holding of safety stock, lot-sizing choices, and the possible use of MRP for unfinished products.

Safety Stock

Theoretically, inventory systems with dependent demand should not require safety stock below the end item level. This is one of the main advantages of an MRP approach. Supposedly, safety stock is not needed because the manager can project precise usage quantities once the master schedule has been established because demand is not variable. Practically, however, there may be exceptions. For example, a bottleneck process or one with varying scrap rates can cause shortages in downstream operations. Furthermore, shortages may occur if orders are late or fabrication or assembly times are longer than expected. On the surface, these conditions lend themselves to the use of safety stock to maintain smooth operations; but the problem becomes more complicated when dealing with multiechelon items (i.e., multiple-level arenas such as assembled products) because a shortage of *any* component will prevent manufacture of the final assembly. However, a major advantage of MRP is lost by holding safety stock for all lower-level items.

MRP systems deal with these problems in several ways. The manager's first step is to identify activities or operations that are subject to variability and to determine the extent of that variability. When lead times are variable, the concept of safety *time* instead of safety *stock* is often used. This results in scheduling orders for arrival or completion sufficiently ahead of the time they are needed in order to eliminate or substantially reduce the element of chance in waiting for those items. When quantities tend to vary, some safety stock may be called for, but the manager must carefully weigh the need and cost of carrying extra stock. Frequently, managers elect to carry safety stock for end items, which are subject to random demand, and for selected lower-level operations when safety time is not feasible.

It is important in general to make sure that lead times are accurate, particularly when the objective is to have incoming shipments of parts and materials arrive shortly before they are needed. Early arrivals increase on-hand inventory and carrying costs, but late arrivals can raise havoc, possibly delaying all following operations. Knowing this, managers may inflate lead times (i.e., use safety time) and cause early arrivals, defeating the objective of matching the arrival of orders with production schedules.

If safety stock is needed, planned order release amounts can be increased by the safety stock quantities for the designated components.

Lot Sizing

Determining a lot size to order or to produce is an important issue in inventory management for both independent- and dependent-demand items. This is called **lot sizing.** For independent-demand items, managers often use economic order sizes and economic production quantities. For dependent-demand systems, however, a much wider variety of plans is used to determine lot sizes, mainly because no single plan has a clear advantage over the others. Some of the most popular plans for lot sizing are described in this section.

lot sizing Choosing a lot size for ordering or production.

A primary goal of inventory management for both independent- and dependent-demand systems is to minimize the sum of ordering cost (or setup cost) and holding cost. With independent demand, that demand is frequently distributed uniformly throughout the planning horizon (e.g., six months, year). Demand tends to be much more lumpy for dependent demand, and the planning horizon shorter (e.g., three months), so that economic lot sizes are usually much more difficult to identify. Consider the situation depicted in Figure 13.13. Period demands vary from 1 to 80 units, and no demand size repeats over the horizon shown.

Managers can realize economies by grouping orders. This would be the case if the additional cost incurred by holding the extra units until they were used led to a savings in setup or ordering cost. This determination can be very complex at times, for several reasons. First, combining period demands into a single order, particularly for middle-level or end items, has a cascading effect down through the product tree: To achieve this grouping, it becomes necessary to also group items at lower levels in the tree and incorporate their setup and holding costs into the decision. Second, the uneven period demand and the relatively short planning horizon require a continual recalculation and updating of lot sizes. Not surprisingly, the methods used to handle lot sizing range from the complex, which attempt to include all relevant costs, to the very simple, which are easy to use and understand. In certain cases, the simple models seem to approach cost minimization although generalizations are difficult. Let's consider some of these models.

Lot-for-Lot Ordering Perhaps the simplest of all the methods is lot-for-lot ordering. The order or run size for each period is set equal to demand for that period. Example 2 demonstrated this method. Not only is the order size obvious, it also virtually eliminates holding costs for parts carried over to other periods. Hence, lot-for-lot ordering minimizes investment in inventory. Its two chief drawbacks are that it usually involves many different order sizes and thus cannot take advantage of the economies of fixed order size (e.g., standard containers and other standardized procedures), and it requires a new setup for each production run. If setup costs can be significantly reduced, this method may approximate a minimum-cost lot size.

Economic Order Quantity Model Sometimes economic order quantity (EOQ) models are used. They can lead to minimum costs if usage is fairly uniform. This is sometimes the case for lower-level items that are common to different parents and for raw materials. However, the more lumpy demand is, the less appropriate such an approach is. Since demand tends to be most lumpy at the end item level, EOQ models tend to be less useful for end items than for items and materials at the lowest levels.

Fixed-Period Ordering This type of ordering provides coverage for some predetermined number of periods (e.g., two or three). In some instances, the span is simply arbitrary; in other cases, a review of historical demand patterns may lead to a more rational designation of a fixed period length. A simple rule is: Order to cover a two-period interval. The rule can be modified when common sense suggests a better way. For example, take a look at the demands shown in Figure 13.13. Using a two-period rule, an order size of 120 units would cover the first two periods. The next two periods would be covered by an order size of 81 units. However, the demands in periods 3 and 5 are so small, it would make sense to combine them both with the 80 units and order 85 units.

FIGURE 13.13

Demand for part K

	Period				
	1	2	3	4	5
Demand	70	50	1	80	4
Cumulative demand	70	120	121	201	205

MRP IN SERVICES

MRP has applications in services as well as in manufacturing. These applications may involve material goods that form a part of the product–service package, or they may involve mainly service components.

An example of a product–service package is a food catering service, particularly in instances that require preparing and serving meals for large numbers of people. To estimate quantities and costs of an order, the food manager would have to determine the quantities of the ingredients for each recipe on the menu (i.e., a bill of materials), which would then be combined with the number of each meal to be prepared to obtain a material requirements plan for the event.

Similar examples occur for large-scale renovations, such as a sports stadium or a major hotel, where there are multiple repetitions of activities and related materials that must be "exploded" into their components for purposes of cost estimation and scheduling.

BENEFITS AND REQUIREMENTS OF MRP

Benefits MRP offers a number of benefits for the typical manufacturing or assembly type of operation, including

1. Low levels of in-process inventories.
2. The ability to keep track of material requirements.
3. The ability to evaluate capacity requirements generated by a given master schedule.
4. A means of allocating production time.

A range of people in a typical manufacturing company are important users of the information provided by an MRP system. Production planners are obvious users of MRP. Production managers, who must balance workloads across departments and make decisions about scheduling work, and plant foremen, who are responsible for issuing work orders and maintaining production schedules, also rely heavily on MRP output. Other users include customer service representatives, who must be able to supply customers with projected delivery dates; purchasing managers; and inventory managers. The benefits of MRP depend in large measure on the use of a computer to maintain up-to-date information on material requirements.

Requirements In order to implement and operate an effective MRP system, it is necessary to have

1. A computer and the necessary software programs to handle computations and maintain records.
2. Accurate and up-to-date
   a. Master schedules
   b. Bills of materials
   c. Inventory records
3. Integrity of file data.

Accuracy is absolutely essential for a successful MRP system. Inaccuracies in inventory record files or bills-of-material files can lead to unpleasant surprises, ranging from missing parts to ordering too many of some items and too few of others, and failure to stay on schedule, all of which contribute to inefficient use of resources, missed delivery dates, and poor customer service.

MRP II

MRP was developed as a way for manufacturing companies to calculate more precisely what materials were needed to produce a product, and when and how much of those materials were needed. **MRP II (manufacturing resources planning)** evolved from MRP in the 1980s because manufacturers recognized additional needs. MRP II did not replace or improve MRP. Rather, it expanded the scope of materials planning to include capacity requirements planning, and to involve other functional areas of the organization such as marketing and finance in the planning process.

manufacturing resources planning (MRP II) Expanded approach to production resource planning, involving other areas of a firm in the planning process and enabling capacity requirements planning.

Material requirements planning is at the heart of the process (see Figure 13.14). The process begins with an aggregation of demand from all sources (e.g., firm orders, forecasts, safety stock requirements). Production, marketing, and finance personnel work toward developing a master production schedule. Although manufacturing people will have a major input in determining that schedule and a major responsibility for making it work, marketing and finance will also have important inputs and responsibilities. The rationale for having these functional areas work together is the increased likelihood of developing a plan that works and with which everyone can live. Moreover, because each of these functional areas has been involved in formulating the plan, they will have reasonably good knowledge of the plan and more reason to work toward achieving it.

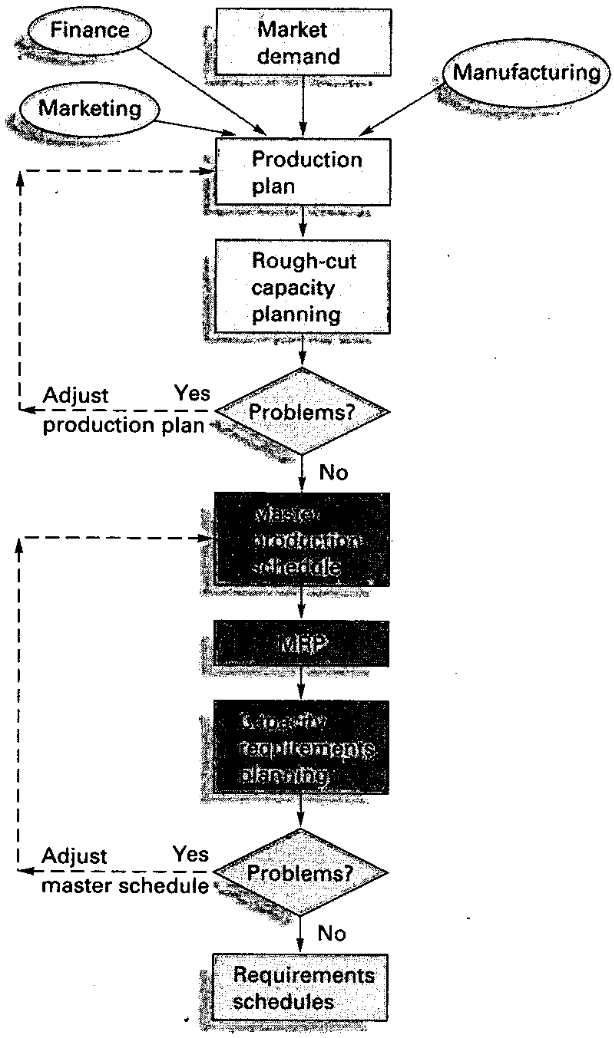


FIGURE 13.14

An overview of MRP II

In addition to the obvious manufacturing resources needed to support the plan, financing resources will be needed and must be planned for, both in amount and timing. Similarly, marketing resources also will be needed in varying degrees throughout the process. In order for the plan to work, the firm must have all of the necessary resources available as needed. Often, an initial plan must be revised based on an assessment of the availability of various resources. Once these have been decided, the master production schedule can be firmed up.

At this point, material requirements planning comes into play, generating material and schedule requirements. Next, management must make more detailed capacity requirements planning to determine whether these more specific capacity requirements can be met. Again, some adjustments in the master production schedule may be required.

As the schedule unfolds and actual work begins, a variety of reports help managers to monitor the process and to make any necessary adjustments to keep operations on track.

In effect, this is a continuing process, where the master production schedule is updated and revised as necessary to achieve corporate goals. The business plan that governs the entire process usually undergoes changes too, although these tend to be less frequent than the changes made at lower levels (i.e., the master production schedule).

Most MRP II systems have the capability of performing simulation, enabling managers to answer a variety of "what if" questions so they can gain a better appreciation of available options and their consequences.

CAPACITY REQUIREMENTS PLANNING

One of the most important features of MRP II is its ability to aid managers in capacity planning.

Capacity requirements planning is the process of determining short-range capacity requirements. The necessary inputs include planned-order releases for MRP, the current shop load, routing information, and job times. Key outputs include load reports for each work center. When variances (underloads or overloads) are projected, managers might consider remedies such as alternative routings, changing or eliminating of lot sizing or safety stock requirements, and lot splitting. Moving production forward or backward can be extremely challenging because of precedence requirements and the availability of components.

capacity requirements planning The process of determining short-range capacity requirements.

A firm usually generates a master schedule initially in terms of what is needed and not what is possible. The initial schedule may or may not be feasible given the limits of the production system and availability of materials when end items are translated into requirements for procurement, fabrication, and assembly. Unfortunately, the MRP system cannot distinguish between a feasible master schedule and a nonfeasible one. Consequently, it is often necessary to run a proposed master schedule through MRP processing in order to obtain a clearer picture of actual requirements, which can then be compared to available capacity and materials. If it turns out that the current master schedule is not feasible, management may make a decision to increase capacity (e.g., through overtime or subcontracting) or to revise the master schedule. In the latter case, this may entail several revisions, each of which is run through the system until a feasible plan is obtained. At that point, the master schedule is *frozen,* at least for the near term, thus establishing a firm schedule from which to plan requirements.

Stability in short-term production plans is very important; without it, changes in order quantity and/or timing can render material requirements plans almost useless. The term *system nervousness* describes the way a system might react to changes. The reaction can sometimes be greater than the original change. For example, a small change near the top of a product tree can reverberate throughout much of the lower parts of the tree, causing major changes to order quantities and production schedules of many components. That, in turn, might cause queues to form at various portions of the system, leading to late orders, increased work in process, and added carrying costs.

To minimize such problems, many firms establish a series of time intervals, called **time fences,** during which changes can be made to orders. For example, a firm might specify time fences of 4, 8, and 12 weeks, with the nearest fence being the most restrictive and the farthest fence being the least restrictive. Beyond 12 weeks, changes are expected; from 8 to 12 weeks, substitutions of one end item for another may be permitted as long as the components are available and the production plan is not compromised; from 4 to 8 weeks, the plan is fixed, but small changes may be allowed; and the plan is frozen out to the four-week fence.

time fences Series of time intervals during which order changes are allowed or restricted; the nearest fence is most restrictive to change, the farthest is least restrictive.

Some companies use two fences: One is a near-term *demand* fence, and the other is a long-term *planning* fence. For example, the demand fence might be four weeks from the present time while the planning fence might be 10 weeks away. In the near term, customer orders receive precedence over the forecast. The time beyond the planning fence is available for inserting new orders into the master schedule. Between the demand fence and the planning fence, management must make trade-offs when changes are introduced unless excess capacity is expected to be available.

In establishing time fences, a manager must weigh the benefits of stability in the production plan against the possible negative impact on the competitive advantage of being able to quickly respond to new orders.

Figure 13.15 presents an overview of the capacity planning process. The process begins with a proposed or tentative master production schedule that must be tested for feasibility and possibly adjusted before it becomes permanent. The proposed schedule is processed using MRP to ascertain the material requirements the schedule would generate. These are then translated into resource (i.e., capacity) requirements, often in the form of a series of **load reports** for each department or work center, which compares known and expected future capacity requirements with projected capacity availability. Figure 13.16 illustrates the nature of a load report. It shows expected resource requirements (i.e., usage) for jobs currently being worked on,

load reports Department or work center reports that compare known and expected future capacity requirements with projected capacity availability.

FIGURE 13.15

Using MRP to assist in planning capacity requirements

Source: Stephen Love, *Inventory Control* (New York: McGraw-Hill. Reprinted by permission.

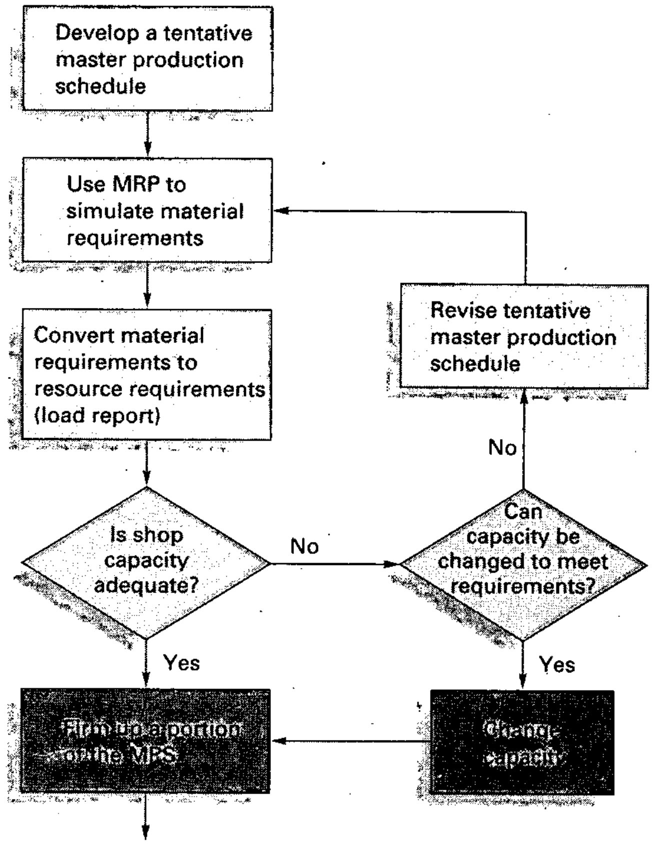
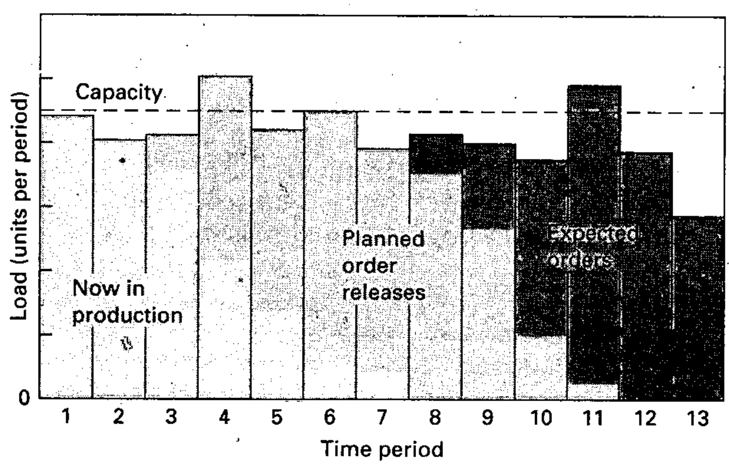


FIGURE 13.16

A hypothetical department load profile



planned orders, and expected orders for the planning horizon. Given this sort of information, the manager can more easily determine whether capacity is sufficient to satisfy these requirements. If there is enough capacity, he or she can freeze the portion of the master production schedule that generates these requirements. In the load profile illustrated in Figure 13.16, planned-order releases in time period 4 will cause an overload. However, it appears possible to accommodate demand by slightly shifting some orders to adjacent periods. Similarly, an overload appears likely in period 11, but that too can be handled by shifting some jobs to adjacent time periods. In cases where capacity is insufficient, a manager may be able to increase capacity (by scheduling overtime, transferring personnel from other areas, or subcontracting some of the work) if this is possible and economical, or else revise the master production schedule and repeat the process until an acceptable production schedule is obtained.

If the master production schedule must be revised, this generally means that the manager must assign priorities to orders, if some orders will be finished later than originally planned.

One note of caution is in order concerning capacity load reports. Often, the load reports are only approximations, and they may not give a true picture because the loading does not take into account scheduling and queuing delays. Consequently, it is possible to experience system backups even though a load report implies sufficient capacity to handle projected loads.

An important aspect of capacity requirements planning is the conversion of quantity requirements into labor and machine requirements. One accomplishes this by multiplying each period's quantity requirements by standard labor and/or machine requirements per unit. For instance, if 100 units of product A are scheduled in the fabrication department, and each unit has a labor standard time of 2 hours and a machine standard time of 1.5 hours, then 100 units of A convert into these capacity requirements:

$$\text{Labor:} \quad 100 \text{ units} \times 2 \text{ hours/unit} = 200 \text{ labor hours}$$

$$\text{Machine:} \quad 100 \text{ units} \times 1.5 \text{ hours/unit} = 150 \text{ machine hours}$$

One can then compare these capacity requirements with available department capacity to determine the extent to which this product utilizes capacity. For example, if the department has 200 labor hours and 200 machine hours available, labor utilization will be 100 percent because all of the labor capacity will be required by this product. However, machine capacity will be underutilized.

$$\frac{\text{Required}}{\text{Available}} \times 100 = \frac{150 \text{ hours}}{200 \text{ hours}} \times 100 = 75 \text{ percent}$$

Underutilization may mean that unused capacity can be used for other jobs; overutilization indicates that available capacity is insufficient to handle requirements. To compensate, production may have to be rescheduled or overtime may be needed.

ERP

ERP (enterprise resource planning) is the next step in an evolution that began with MRP and evolved into MRP II. Like MRP II, it typically has an MRP core. ERP represents an expanded effort to integrate *standardized* record keeping that will permit *information sharing* among different areas of an organization in order to manage the system more effectively. The following reading does an excellent job of describing ERP.

enterprise resource planning (ERP) Integration of financial, manufacturing, and human resources on a single computer system.

The ABCs of ERP

READING

Compiled from Reports by Christopher Koch, Derek Slater, and E. Baatz

- What is ERP?
- How long will an ERP project take?
- What will ERP fix in my business?
- Will ERP fit the way I do business?
- What does ERP really cost?
- When will I get payback from ERP—and how much will it be?
- What are the unforeseen costs of ERP?
- How do you configure ERP software?
- How do companies organize their ERP projects?
- How does ERP fit with electronic commerce?

What Is ERP?

Enterprise resource planning software, or ERP, doesn't live up to its acronym. Forget about planning—it doesn't do that—and forget about resource, a throwaway term. But remember the enterprise part. This is ERP's true ambition. It attempts to integrate all departments and functions across a company onto a single computer system that can serve all those different departments' particular needs.

That is a tall order, building a single software program that serves the needs of people in finance as well as it does the people in human resources and in the warehouse. Each of those departments typically has its own computer system, each optimized for the particular ways that the department does its

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work. But ERP combines them all together into a single, integrated software program that runs off a single database so that the various departments can more easily share information and communicate with each other.

That integrated approach can have a tremendous payback if companies install the software correctly. Take a customer order, for example. Typically, when a customer places an order, that order begins a mostly paper-based journey from in-basket to in-basket around the company, often being keyed and rekeyed into different departments' computer systems along the way. All that lounging around in in-baskets causes delays and lost orders, and all the keying into different computer systems invites errors. Meanwhile, no one in the company truly knows what the status of the order is at any given point because there is no way for the finance department, for example, to get into the warehouse's computer system to see whether the item has been shipped. "You'll have to call the warehouse," is the familiar refrain heard by frustrated customers.

How Can ERP Improve a Company's Business Performance?

ERP automates the tasks involved in performing a business process—such as order fulfillment, which involves taking an order from a customer, shipping it and billing for it. With ERP, when a customer service representative takes an order from a customer, he or she has all the information necessary to complete the order (the customer's credit rating and order history, the company's inventory levels and the shipping dock's trucking schedule). Everyone else in the company sees the same computer screen and has access to the single database that holds the customer's new order. When one department finishes with the order it is automatically routed via the ERP system to the next department. To find out where the order is at any point, one need only log into the ERP system and track it down. With luck, the order process moves like a bolt of lightning through the organization, and customers get their orders faster and with fewer mistakes than before. ERP can apply that same magic to the other major business processes, such as employee benefits or financial reporting.

That, at least, is the dream of ERP. The reality is much harsher.

Let's go back to those inboxes for a minute. That process may not have been efficient, but it was simple. Finance did its job, the warehouse did its job, and if anything went wrong outside of the department's walls, it was somebody else's problem. Not anymore. With ERP, the customer service representatives are no longer just typists entering someone's name into a computer and hitting the return key. The ERP screen makes them business people. It flickers with the customer's credit rating from the finance department and the product inventory levels from the warehouse. Will the customer pay on time? Will we be able to ship the order on time? These are decisions that customer service representatives have never had to make before and which affect the customer and every other department in the company. But it's not just the customer service representatives who have to wake up. People in the warehouse who used to keep inventory in their heads or on scraps of paper now need to put that information online. If they don't, customer service will see low inventory levels on their screens and tell customers that their requested item is not in stock. Accountability, responsibility and communication have never been tested like this before.

How Long Will an ERP Project Take?

Companies that install ERP do not have an easy time of it. Don't be fooled when ERP vendors tell you about a three or six month average implementation time. Those short (that's right, six months is short) implementations all have a catch of one kind or another: the company was small, or the implementation was limited to a small area of the company, or the company only used the financial pieces of the ERP system (in which case the ERP system is nothing more than a very expensive accounting system). To do ERP right, the ways you do business will need to change and the ways people do their jobs will need to change too. And that kind of change doesn't come without pain. Unless, of course, your ways of doing business are working extremely well (orders all shipped on time, productivity higher than all your competitors, customers completely satisfied), in which case there is no reason to even consider ERP.

The important thing is not to focus on how long it will take—real transformational ERP efforts usually run between one to three years, on average—but rather to understand why you need it and how you will use it to improve your business.

What Will ERP Fix in My Business?

There are three major reasons why companies undertake ERP:

To integrate financial data—As the CEO tries to understand the company's overall performance, he or she may find many different versions of the truth. Finance has its own set of revenue numbers, sales has another version, and the different business units may each have their own versions of how much they contributed to revenues. ERP creates a single version of the truth that cannot be questioned because everyone is using the same system.

To standardize manufacturing processes—Manufacturing companies—especially those with an appetite for mergers and acquisitions—often find that multiple business units across the company make the same widget using different methods and computer systems. Standardizing those processes and using a single, integrated computer system can save time, increase productivity and reduce headcount.

To standardize HR information—Especially in companies with multiple business units, HR may not have a unified, simple method for tracking employee time and communicating with them about benefits and services. ERP can fix that.

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In the race to fix these problems, companies often lose sight of the fact that ERP packages are nothing more than generic representations of the ways a typical company does business. While most packages are exhaustively comprehensive, each industry has its quirks that make it unique. Most ERP systems were designed to be used by discreet manufacturing companies (who make physical things that can be counted), which immediately left all the process manufacturers (oil, chemical and utility companies that measure their products by flow rather than individual units) out in the cold. Each of these industries has struggled with the different ERP vendors to modify core ERP programs to their needs.

Will ERP Fit the Ways I Do Business?

It's critical for companies to figure out if their ways of doing business will fit within a standard ERP package before the checks are signed and the implementation begins. The most common reason that companies walk away from multimillion dollar ERP projects is that they discover that the software does not support one of their important business processes. At that point there are two things they can do: They can change the business process to accommodate the software, which will mean deep changes in long-established ways of doing business (that often provide competitive advantage) and shake up important peoples' roles and responsibilities (something that few companies have the stomach for). Or they can modify the software to fit the process, which will slow down the project, introduce dangerous bugs into the system and make upgrading the software to the ERP vendor's next release excruciatingly difficult, because the customizations will need to be torn apart and rewritten to fit with the new version.

Needless to say, the move to ERP is a project of breathtaking scope, and the price tags on the front end are enough to make the most placid CFO a little twitchy. In addition to budgeting for software costs, financial executives should plan to write checks to cover consulting, process rework, integration testing and a long laundry list of other expenses before the benefits of ERP start to manifest themselves. Underestimating the price of teaching users their new job processes can lead to a rude shock down the line. So can failure to consider data warehouse integration requirements and the cost of extra software to duplicate the old report formats. A few oversights in the budgeting and planning stage can send ERP costs spiraling out of control faster than oversights in planning almost any other information system undertaking.

What Does ERP *Really* Cost?

Meta Group recently did a study looking at the Total Cost of Ownership (TCO) of ERP, including hardware, software, professional services, and internal staff costs. The TCO numbers include getting the software installed and the two years afterward, which is when the real costs of maintaining, upgrading and optimizing the system for your business are felt. Among the 63 companies surveyed—including small, medium and large companies in a range of industries—the average TCO was $15 million (the highest was $300 million and lowest was $400,000). While it's hard to draw a solid number from that kind of a range of companies and ERP efforts, Meta came up with one statistic that proves that ERP is expensive no matter what kind of company is using it. The TCO for a "heads-down" user over that period was a staggering $53,320.

When Will I Get Payback from ERP—and How Much Will It Be?

Don't expect to revolutionize your business with ERP. It is a navel gazing exercise that focuses on optimizing the way things are done internally rather than with customers, suppliers or partners. Yet the navel gazing has a pretty good payback if you're willing to wait for it—a Meta Group study of 63 companies found that it took eight months after the new system was in (31 months total) to see any benefits. But the median annual savings from the new ERP system was $1.6 million per year.

The Hidden Costs of ERP

Although different companies will find different land mines in the budgeting process, those who have implemented ERP packages agree that certain costs are more commonly overlooked or underestimated than others. Armed with insights from across the business, ERP pros vote the following areas as most likely to result in budget overrun.

1. *Training.* Training is the near-unanimous choice of experienced ERP implementers as the most elusive budget item. It's not so much that this cost is completely overlooked as it is consistently underestimated. Training expenses are high because workers almost invariably have to learn a new set of processes, not just a new software interface.
2. *Integration and testing.* Testing the links between ERP packages and other corporate software links that have to be built on a case-by-case basis is another often underestimated cost. A typical manufacturing company may have add-on applications for logistics, tax, production planning and bar coding. If this laundry list also includes customization of the core ERP package, expect the cost of integrating, testing and maintaining the system to skyrocket.

   As with training, testing ERP integration has to be done from a process-oriented perspective. Instead of plugging in dummy data and moving it from one application to the next, veterans recommend running a real purchase order through the system, from order entry through shipping and receipt of payment—the whole order-to-cash banana—preferably with the participation of the employees who will eventually do those jobs.
3. *Data conversion.* It costs money to move corporate information, such as customer and supplier records, product design data and the like, from old systems to new ERP homes.

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Although few CIOs will admit it, most data in most legacy systems is of little use. Companies often deny their data is dirty until they actually have to move it to the new client/server setups that popular ERP packages require. Consequently, those companies are more likely to underestimate the cost of the move. But even clean data may demand some overhaul to match process modifications necessitated—or inspired—by the ERP implementation.

4. *Data analysis.* Often, the data from the ERP system must be combined with data from external systems for analysis purposes. Users with heavy analysis needs should include the cost of a data warehouse in the ERP budget—and they should expect to do quite a bit of work to make it run smoothly. Users are in a pickle here: Refreshing all the ERP data in a big corporate data warehouse daily is difficult, and ERP systems do a poor job of indicating which information has changed from day to day, making selective warehouse updates tough. One expensive solution is custom programming. The upshot is that the wise will check all their data analysis needs before signing off on the budget.
5. *Consultants ad infinitum.* When users fail to plan for disengagement, consulting fees run wild. To avoid this, companies should identify objectives for which [their] consulting partners must aim when training internal staff. Include metrics in the consultants' contract; for example, a specific number of the user company's staff should be able to pass a project-management leadership test—similar to what Big Five consultants have to pass to lead an ERP engagement.
6. *Replacing your best and brightest.* ERP success depends on staffing the project with the best and brightest from the business and IS. The software is too complex and the business changes too dramatic to trust the project to just anyone. The bad news is, a company must be prepared to replace many of those people when the project is over. Though the ERP market is not as hot as it once was, consulting firms and other companies that have lost their best people will be hounding yours with higher salaries and bonus offers than you can afford—or that your HR policies permit. Huddle with HR early on to develop a retention bonus program and to create new salary strata for ERP veterans. If you let them go, you'll wind up hiring them—or someone like them—back as consultants for twice what you paid them in salaries.
7. *Implementation teams can never stop.* Most companies intend to treat their ERP implementations as they would any other software project. Once the software is installed, they figure, the team will be scuttled and everyone will go back to his or her day job. But after ERP, you can't go home again. You're too valuable. Because they have worked intimately with ERP, they know more about the sales process than the salespeople do and more about the manufacturing process than the manufacturing people do. Companies can't afford to send their project people back into the business because there's so much to do after the ERP software is installed. Just writing reports to pull information out of the new ERP system will keep the project team busy for a year at least. And it is in analysis—and, one hopes, insight—that companies make their money back on an ERP implementation. Unfortunately, few IS departments plan for the frenzy of post-ERP installation activity, and fewer still build it into their budgets when they start their ERP projects. Many are forced to beg for more money and staff immediately after the go-live date, long before the ERP project has demonstrated any benefit.
8. *Waiting for ROI.* One of the most misleading legacies of traditional software project management is that the company expects to gain value from the application as soon as it is installed; the project team expects a break, and maybe a pat on the back. Neither expectation applies to ERP. Most don't reveal their value until after companies have had them running for some time and can concentrate on making improvements in the business processes that are affected by the system. And the project team is not going to be rewarded until their efforts pay off.
9. *Post-ERP depression.* ERP systems often wreak havoc in the companies that install them. In a recent Deloitte Consulting survey of 64 Fortune 500 companies, one in four admitted that they suffered a drop in performance when their ERP systems went live. The true percentage is undoubtedly much higher. The most common reason for the performance problems is that everything looks and works differently from the way it did before. When people can't do their jobs in the familiar way and haven't yet mastered the new way, they panic, and the business goes into spasms.

How Do You Configure ERP Software?

Even if a company installs ERP software for the so-called right reasons and everyone can agree on the optimal definition of a customer, the inherent difficulties of implementing something as complex as ERP is like, well, teaching an elephant to do the hootchy-kootchy. The packages are built from database tables, thousands of them, that IS programmers and end users must set to match their business processes; each table has a decision "switch" that leads the software down one decision path or another. By presenting only one way for the company to do each task—say, run the payroll or close the books—a company's individual operating units and far-flung divisions are integrated under one system. But figuring out precisely how to set all the switches in the tables requires a deep understanding of the existing processes being used to operate the business. As the table settings are decided, these business processes are reengineered, ERP's way. Most ERP systems are not shipped as a shell system in which customers must determine at the minutia level how all the functional procedures should be set, making thousands of decisions that affect how their system behaves in line with their own business activities. Most ERP systems are preconfigured, allowing just hundreds—rather than thousands—of procedural settings to be made by the customer.

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How Do Companies Organize Their ERP Projects?

Based on our observations, there are three commonly used ways of installing ERP.

The big bang—In this, the most ambitious and difficult of approaches to ERP implementation, companies cast off all their legacy systems at once and implement a single ERP system across the entire company.

Though this method dominated early ERP implementations, few companies dare to attempt it anymore because it calls for the entire company to mobilize and change at once. Most of the ERP implementation horror stories from the late '90s warn us about companies that used this strategy. Getting everyone to cooperate and accept a new software system at the same time is a tremendous effort, largely because the new system will not have any advocates. No one within the company has any experience using it, so no one is sure whether it will work. Also, ERP inevitably involves compromises. Many departments have computer systems that have been honed to match the ways they work. In most cases, ERP offers neither the range of functionality, nor the comfort of familiarity that a custom legacy system can offer. In many cases, the speed of the new system may suffer because it is serving the entire company rather than a single department. ERP implementation requires a direct mandate from the CEO.

Franchising strategy—This approach suits large or diverse companies that do not share many common processes across business units. Independent ERP systems are installed in each unit, while linking common processes, such as financial bookkeeping, across the enterprise.

This has emerged as the most common way of implementing ERP. In most cases, the business units each have their own "instances" of ERP—that is, a separate system and database. The systems link together only to share the information necessary for the corporation to get a performance big picture across all the business units (business unit revenues, for example), or for processes that don't vary much from business unit to business unit (perhaps HR benefits). Usually, these implementations begin with a demonstration or "pilot" installation in a particularly open-minded and patient business unit where the core business of the corporation will not be disrupted if something goes wrong. Once the project team gets the system up and running and works out all the bugs, the team begins selling other units on ERP, using the first implementation as a kind of in-house customer reference. Plan for this strategy to take a long time.

Slam-dunk—ERP dictates the process design in this method, where the focus is on just a few key processes, such as those contained in an ERP system's financials module. The slam-dunk is generally for smaller companies expecting to grow into ERP.

The goal here is to get ERP up and running quickly and to ditch the fancy reengineering in favor of the ERP system's "canned" processes. Few companies that have approached ERP this way can claim much payback from the new system. Most use it as an infrastructure to support more diligent installation efforts down the road. Yet many discover that a slammed-in ERP system is little better than a legacy system, because it doesn't force employees to change any of their old habits. In fact, doing the hard work of process reengineering after the system is in can be more challenging than if there had been no system at all, because at that point few people in the company will have felt much benefit.

How Does ERP Fit with Electronic Commerce?

After all of that work inventing, perfecting and selling ERP to the world, the major ERP vendors are having a hard time shifting gears from making the applications that streamline business practices inside a company to those that face outward to the rest of the world. These days, the hottest areas for outward-looking (that is, Internet) post-ERP work are electronic commerce, planning and managing your supply chain, and tracking and serving customers. Most ERP vendors have been slow to develop offerings for these areas, and they face stiff competition from niche vendors. ERP vendors have the advantage of a huge installed base of customers and a virtual stranglehold on the "back office" functions—such as order fulfillment. Recently ERP vendors have begun to shrink their ambitions and focus on being the back-office engine that powers electronic commerce, rather than trying to own all the software niches that are necessary for a good electronic commerce Website. Indeed, as the niche vendors make their software easier to hook into electronic commerce Websites, and as middleware vendors make it easier for IS departments to hook together applications from different vendors, many people wonder how much longer ERP vendors can claim to be the primary platform for the Fortune 500.

Questions

1. What is ERP?
2. What are the three main reasons firms adopt ERP?
3. What are some hidden costs of ERP?
4. How does ERP fit with e-commerce and supply chain management?

Source: "The ABCs of ERP," compiled from Reports by Christopher Koch, Derek Slater, and E. Baatz, Cio.com, December 22, 1999.

ERP is now about enterprise applications *integration*, an issue that generally arises with any major technology acquisition. The following reading underscores this point.

[Condensed from] The Top 10 ERP Mistakes READING

Clive Weightman

Although faulty technology often is blamed for problems, it is frequently other shortcomings that create performance-related problems—such as the people employing the ERP application don't fully understand what it is or how it works.

Execution of a successful ERP project provides the backbone for a company's internal and external operations—from integrating back-office financials with business performance data to building a launch platform for an extended enterprise and collaborative commerce. This foundation can serve as the competitive weapon of the future.

Top 10 Mistakes

10. *Believing the journey is complete at "go live."* Treat the day your ERP project goes live as the start of the next phase of your journey, not the finish because an ERP implementation represents much more than simply a project. . . . So don't disband the team a month after the project goes live.
9. *Not planning for—and minimizing—the interim performance dip after start up.* Research shows that even the projects that have gone the smoothest in the execution stage suffer a dip in performance after the new system launches. Transactional efficiency, the pace of taking sales orders may slow down, or the speed of pushing products into the warehouse may decline a bit. Recognize that performance is going to suffer some at the outset, but with excellent execution, this effect can be very slim and very short.
8. *Failing to balance the needs and power of integration with seeking quick business hits.* Today, every chief executive officer must deliver results now, not in 15 months from now. Given the challenges of a full ERP implementation, it's difficult for them to promise their board of directors that with the ERP project, they are going to see savings in 24 to 36 months of such-and-such amount. They want to see the return on investment now.
7. *Starting too late to address all things data (architecture, standards, management, cleansing, and so on).* These systems are only as good as the fundamental data that enters them. And that's where a common problem erupts. Far too often, research indicates, companies think about the quality and accuracy of their data too late in the project. The consistency and accuracy of data is [sic] critical.
6. *Failing to staff the team with "A" players from business and technical sides of the organization, including program management.* This can be a major challenge. You need top-notch players for these projects—not just technical stars but stellar performers from the business side as well. Indeed, if you have to trade off in terms of quality in one area, never skimp on business talent. You can perhaps trade off on technical expertise because the consultant you retain can bring in skilled technicians.

   And the "A" players should encompass program managers to the most junior members of the team.
5. *Starting without an effective and dedicated senior governance council, including a single executive sponsor.* Any major ERP project overhauls a lot of business processes, roles, responsibilities, standards, and data definitions—and these are changes that cannot be pursued from the bottom up. An effective governing council—a steering group—is essential, as is a single executive sponsor, dedicated and effective, to chair it. The project will trigger difficult, sometimes nasty, issues and a senior executive who is accountable can make those decisions and see that the steering group understands and accepts them.

   The project's executive "angel" must be from the corporate suite and, preferably, not the chief information officer.
4. *Selecting a strong systems integrator and then not heeding its advice.* In selecting an SI, a company should:
   - Consider compatibility. Do you want a firm that wants to come in to do it to you rather than do it with you? Some SI firms favor a "let's solve this together" approach, while others prefer the "here are your marching orders, this is how it's going to be, so let's get down to business." Determine which approach you favor for your firm's culture.
   - Clearly look at the SI's track record. Look beyond its marketing, talk to the software vendors you'll be working with and also talk with industry analysts.
   - Spend considerable time examining the members of the actual team that will be working with you every day. Be sure to put language in the contract that at least binds the team leaders and the firm's partner with you for its duration.
3. *Trying to create a solution incompatible with the company's culture.* In the 1990s, research found that many companies with ERP projects saw them as a silver bullet that would solve all their problems—even if the "style" of solution wasn't compatible with their corporate culture traditions.

   An executive might say he or she wants to operate in a globally centralized fashion—to be more like a Wal-Mart, with the strength and discipline of a global head office. However, this doesn't work if your firm's culture is one of decentralized entrepreneurship. You can't use technology to force change in the culture of your company. So if yours is a very decentralized structure, you'd better opt to install a decentralized ERP application or recognize the enormous change-management mountain you face.
2. *Treating this as a technical project vs. a change that balances people, process, and technology; not using the*

(continued)

(concluded)

power of the new, integrated information. The new technology brings integration and, generally, makes information available instantly. For example, when raw material arrives at a company's receiving dock and is scanned into the system, anyone can access that information and use it.

Real-time integration and accurate data change people's jobs. A traditional sales order taker can change into a full-service customer agent. For example, with full online access to an integrated ERP backbone, the agent enjoys immediate access to the customer's history and other vital identifiers. The agent can examine real-time open inventory at all warehouses (not just local) and future production schedules. The agent can freeze and commit from this schedule to the customer's immediate needs, among other things.

1. *Embarking on the journey without a solid, approved business case, including mechanisms to update the business case continuously and to ensure the savings are baked into operational budgets.* Since an ERP project is going to take a minimum of 12 months and as much as 36 months to employ, and often costs between $5 million and $50 million out-of-pocket costs, stamina is essential. So you must be absolutely certain why you're embarking on this journey; that is, have a solid business case.

   At the same time, if a solid business case hasn't been made for the project, you won't get the commitment from the entire business team to make the journey successful. Many times when a company pursues an ERP implementation, it isn't simply to cut technology costs, because total technical costs may well increase with the application. Most of the time, the project is undertaken for broader business reasons, so if those reasons aren't clearly expressed, fully understood, and approved in both qualitative and quantitative terms, members of the senior executive team won't give their full support.

   While this is far less of an issue than it was five years ago, a number of major companies still complete the business case for an ERP project, submit a capital appropriation request, eventually get it approved, only to park the business case on the shelf to gather dust while the project proceeds.

   A business case should be a living, breathing document of how to drive out both the original and updated business benefits from the ERP journey for, say, the next 20 years. It must outline how to track the benefits the application will produce, and it must be used for the CEO to bake into the annual operating budgets the cost-reductions and revenue increases that each vice president has committed to. It must make senior and middle executives accountable for the goals so that the anticipated bottom-line benefits are realized. This type of discipline still is relatively rare, in part because many managers think, "Hey, I'm not going to be here to see the end of this."

   But, for an ERP project to succeed, it is critical that this business case is documented and becomes well worn. Just how vital is it? It does head this list of mistakes to avoid!

Source: Condensed from "The Top 10 ERP Mistakes," Clive Weightman and Deloitte Consulting. Copyright © Clive Weightman. Used with permission.

Operations Strategy

Acquisition of technology on the order of ERP has strategic implications. Among the considerations are a high initial cost, a high cost to maintain, the need for future upgrades, and the intensive training required. An ERP team is an excellent example of the value of a cross-functional team. Purchasing, which will ultimately place the order, typically does not have the technical expertise to select the best vendor. Information technology can assess various technical requirements, but won't be the user. Various functional users (marketing, operations, and accounting) will be in the best position to evaluate inputs and outputs, and finance must evaluate the effect on the organization's bottom line. Also, it is important to have a member of the purchasing staff involved from the beginning of negotiations on ERP acquisition because this will have major implications for purchasing.

SUMMARY

MRP is a planning technique that creates a schedule for all the (dependent-demand) items in an end item's bill of materials based on fixed manufacturing lead times. The end item is exploded using the bill of materials, and material requirements plans are developed that show quantity and timing for ordering or producing components.

The main features of MRP are the time-phasing of requirements, calculating component requirements, and planned-order releases. To be successful, MRP requires accurate master production schedules, bills of materials, and inventory data. Firms without reasonably accurate records or schedules have experienced major difficulties in trying to implement MRP-type systems.

MRP is utilized by most MRP II and ERP systems. MRP II adds software applications designed to better manage the entire manufacturing process involving finance and marketing, and including capacity planning. ERP is the third generation of manufacturing software that encompasses all business functions, including order entry and an option for financial management *integrated* with the manufacturing functions available in MRP II.

KEY TERMS

bill of materials (BOM), 578
capacity requirements planning, 593
changes, 588
cumulative lead time, 578
dependent demand, 575
enterprise resource planning (ERP), 595
exception reports, 588
gross requirements, 582
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load reports, 593
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manufacturing resources planning (MRP II), 591
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material requirements planning (MRP), 576
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planned-order receipts, 582
planned-order releases, 582
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planning reports, 588
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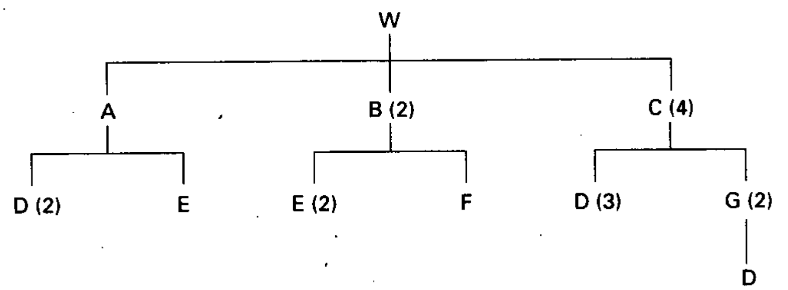
regenerative system, 588
scheduled receipts, 582
time fences, 593

SOLVED PROBLEMS

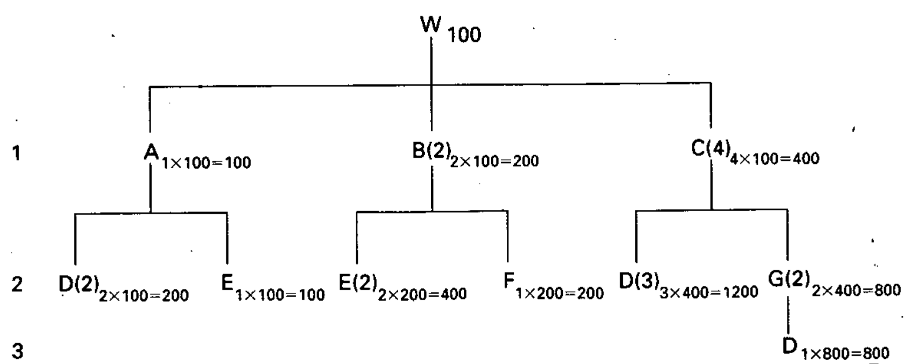
Problem 1

The following product structure tree indicates the components needed to assemble one unit of product W. Determine the quantities of each component needed to assemble 100 units of W.



Solution

An easy way to compute and keep track of component requirements is to do it right on the tree, as shown in the following figure. Note: for the procedure when there are on-hand inventories, see Example 2, page 580.

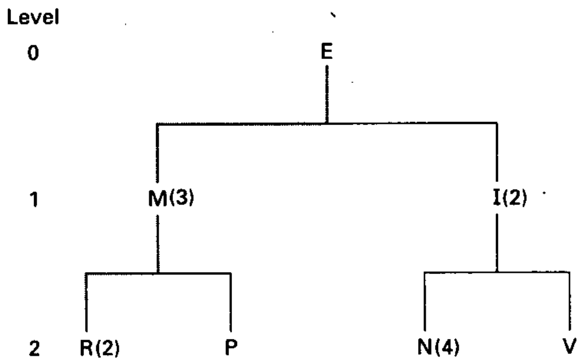


Summary:

Level	Item	Quantity
0	W	100
1	A	100
	B	200
	C	400
2	E	500
	F	200
	G	800
3	D	2,200

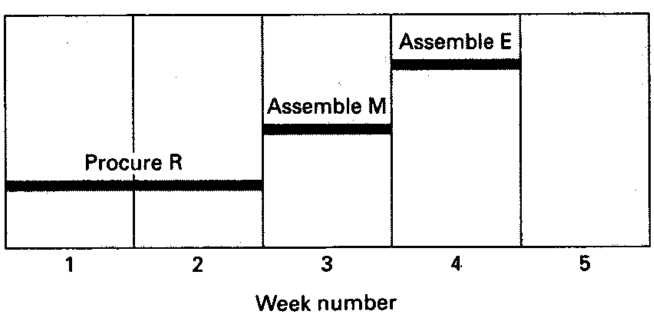
Problem 2

The product structure tree for end item E follows. The manager wants to know the material requirements for ordered part R that will be needed to complete 120 units of E by the start of week 5. Lead times for items are one week for level 0 items, one week for level 1 items, and two weeks for level 2 items. There is a scheduled receipt of 60 units of M at the *end* of week 1 and 100 units of R at the *start* of week 1. Lot-for-lot ordering is used.



Solution

A partial assembly-time chart that includes R and leads to completion of E by the start of week 5 looks like this:



The table entries are arrived at as follows:

Master schedule: 120 units of E to be available at the start of week 5.

Item E: Gross requirements equal the quantity specified in the master production schedule. Since there is no on-hand inventory, net requirements also equal 120 units. Using lot-for-lot ordering, 120 units must be scheduled to be available at the start of week 5. Because there is a one-week lead time for assembly of Es, an order will need to be released (i.e., work started) at the beginning of week 4.

Item M: The *gross* requirements for M are three times the *net* requirements for E, because each E requires three Ms. These must be available at the start of week 4. The net requirements are 60 units less due to the 60 units expected to be on hand at that time. Hence, 300 additional units of M must be available at the start of week 4. With the one-week lead time, there must be an order release at the start of week 3.

Item R: Because each M requires two units of R, 600 Rs will be needed to assemble 300 units of M. However, 100 units will be on hand, so only 500 need to be ordered. Because there is a lead time of two weeks, the 500 Rs must be ordered at the start of week 1.

The master schedule for E and requirements plans for E, M, and R follow.

Master schedule for E

Week number	Beg. Inv.	1	2	3	4	5
Quantity						120

Item: E LT = 1 week						
Gross requirements						120
Scheduled receipts						
Projected on hand						
Net requirements						120
Planned-order receipts						120
Planned-order releases					120	

Multiplied by 3
(see product tree)

Item: M LT = 1 week						
Gross requirements					360	
Scheduled receipts			60			
Projected on hand			60	60	60	
Net requirements					300	
Planned-order receipts					300	
Planned-order releases				300		

Multiplied by 2
(see product tree)

Item: R LT = 2 weeks						
Gross requirements				600		
Scheduled receipts		100				
Projected on hand		100	100	100		
Net requirements				500		
Planned-order receipts				500		
Planned-order releases		500				

Problem 3

Capacity requirements planning. Given the following production schedule in units and the production standards for labor and machine time for this product, determine the labor and machine capacity requirements for each week. Then compute the percent utilization of labor and machines in each week if labor capacity is 200 hours per week and machine capacity is 250 hours per week.

Production Schedule:

Week	**1**	**2**	**3**	**4**
Quantity	200	300	100	150

Standard Times:

Labor	.5 hour/unit
Machine	1.0 hour/unit

Solution

Convert the quantity requirements into labor and machine requirements by multiplying the quantity requirements by the respective standard times (i.e., multiply each quantity by .5 to obtain the labor hours and multiply each quantity by 1.0 to obtain the machine hours):

Week	**1**	**2**	**3**	**4**
Quantity	200	300	100	150
Labor hours	100	150	50	75
Machine hours	200	300	100	150

To compute utilization, divide the capacity requirements by the available capacity (200 hours per week for labor and 250 hours per week for machine) and multiply by 100. The results are

Week	**1**	**2**	**3**	**4**
Labor	50%	75%	25%	37.5%
Machine	80%	120%	40%	60%

Note that machine capacity in week 2 is overutilized (i.e., capacity is insufficient) because the utilization exceeds 100 percent. To compensate, some production could be shifted to weeks 1 and/or 3 where labor and machine time are available.

DISCUSSION AND REVIEW QUESTIONS

1. Contrast independent and dependent demand.
2. When is MRP appropriate?
3. Briefly define or explain each of these terms.
   a. Master schedule
   b. Bill of materials
   c. Inventory records
   d. Gross requirements
   e. Net requirements
   f. Time-phased plan
4. How is safety stock included in a material requirements plan?
5. What factors can create safety stock requirements in an MRP system?
6. What is meant by the term *safety time?*
7. Contrast *net-change* systems and *regenerative* systems for MRP.
8. Briefly discuss the requirements for effective MRP.
9. What are some of the main advantages and limitations of MRP?
10. How can the use of MRP contribute to productivity?
11. Briefly describe MRP II and indicate how it relates to MRP.
12. What is lot sizing, what is its goal, and why is it an issue with lumpy demand?
13. Contrast planned-order receipts and scheduled receipts.
14. If seasonal variations are present, is their incorporation into MRP fairly simple or fairly difficult? Explain briefly.
15. How does the purpose of ERP differ from the purpose of MRP II?
16. What are some unforeseen costs of ERP?

TAKING STOCK

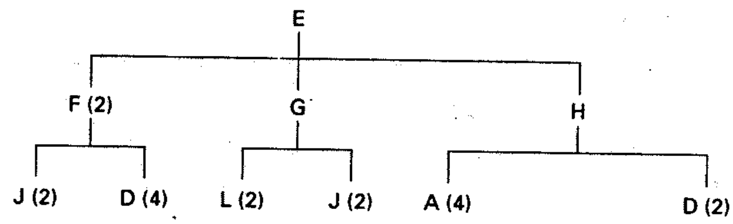
1. What trade-offs are involved in the decision to purchase an ERP software package?
2. Who in the organization needs to be involved in designing and implementing MRP II? Who needs to be involved in the decision to purchase an ERP system? Who needs to be trained to use ERP?
3. To what extent has technology such as ERP software improved the ability to manage a business organization. How important are each of the following considerations?
   a. Ease of use
   b. Complete integration
   c. Reliability

CRITICAL THINKING EXERCISE

Suppose you work for a furniture manufacturer, one of whose products is the chair depicted in Figure 13.5. Finished goods inventory is held in a central warehouse in anticipation of customer orders. Finished goods are controlled using EOQ/ROP methods. The warehouse manager, Juan Villa, has suggested using the same methods for controlling component inventory. Write him a brief memo outlining your opinion on doing that.

PROBLEMS

1. *a.* Given the following diagram for a product, determine the quantity of each component required to assemble one unit of the finished product.

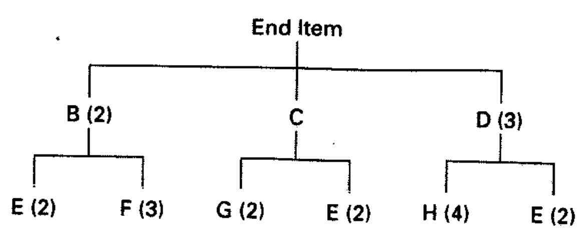


   b. Draw a tree diagram for the stapler:

Item	**Components**
Stapler	Top assembly, base assembly
Top assembly	Cover, spring, slide assembly
Cover	
Spring	
Slide assembly	Slide, spring
Slide	
Spring	
Base assembly	Base, strike plate, rubber pad (2)
Base	
Strike plate	
Rubber pad (2)	

2. The following table lists the components needed to assemble an end item, lead times, and quantities on hand.

Item	End	B	C	D	E	F	G	H
LT (wk)	1	2	3	3	1	2	1	2
Amount on hand	0	10	10	25	12	30	5	0



   a. If 20 units of the end item are to be assembled, how many additional units of E are needed? (*Hint:* You don't need to develop an MRP plan to determine this.)

b. An order for the end item is scheduled to be shipped at the start of week 11. What is the latest week that the order can be started and still be ready to ship on time? (*Hint:* You don't need to develop an MRP plan for this part either.)

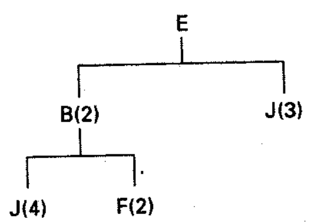
3. The following table lists the components needed to assemble an end item, lead times (in weeks), and quantities on hand.

Item	Lead Time	Amount on Hand	Direct Components
End	1	—	L(2), C(1), K(3)
L	2	10	B(2), J(3)
C	3	15	G(2), B(2)
K	3	20	H(4), B(2)
B	2	30	
J	3	30	
G	3	5	
H	2	—	

a. If 40 units of the end item are to be assembled, how many additional units of B are needed? (*Hint:* You don't need to develop an MRP plan.)

b. An order for the end item is scheduled to be shipped at the start of week 8. What is the latest week that the order can be started and still be ready to ship on time? (*Hint:* You don't need to develop an MRP plan.)

4. Eighty units of end item E are needed at the beginning of week 6. Three cases (30 units per case) of J have been ordered and one case is scheduled to arrive in week 3, one in week 4, and one in week 5. *Note:* J must be ordered by the case, and B must be produced in multiples of 120 units. There are 60 units of B and 20 units of J now on hand. Lead times are two weeks each for E and B, and one week for J.



a. Prepare a material requirements plan for component J.

b. Suppose that in week 4 the quantity of E needed is changed from 80 to 70. The planned order releases through week 3 have all been executed. How many more Bs and Js will be on hand in week 6?

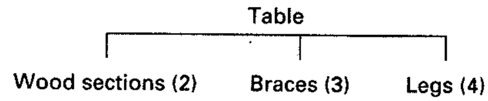
5. End item P is composed of three subassemblies: K, L, and W. K is assembled using 3 Gs and 4 Hs; L is made of 2 Ms and 2 Ns; and W is made of 3 Zs. On-hand inventories are 20 Ls, 40 Gs, and 200 Hs. Scheduled receipts are 10 Ks at the start of week 3, 30 Ks at the start of week 6, and 200 Ws at the start of week 3.

   One hundred Ps will be shipped at the start of week 6, and another 100 at the start of week 7. Lead times are two weeks for subassemblies and one week for components G, H, and M. Final assembly of P requires one week. Include an extra 10 percent scrap allowance in each planned order of G. The minimum order size for H is 200 units. Develop each of the following:

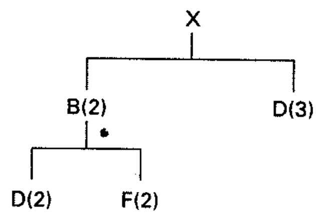
   a. A product structure tree.
   b. An assembly time chart.
   c. A master schedule for P.
   d. A material requirements plan for K, G, and H using lot-for-lot ordering.

6. A table is assembled using three components, as shown in the accompanying product structure tree. The company that makes the table wants to ship 100 units at the beginning of day 4, 150 units at the beginning of day 5, and 200 units at the beginning of day 7. Receipts of 100 wood sections are scheduled at the beginning of day 2. There are 120 legs on hand. An additional 10 percent of the order size on legs is added for safety stock. There are 60 braces on hand with no safety stock requirement for braces. Lead times (in days) for all items are shown in the following table. Prepare a material requirements plan using lot-for-lot ordering.

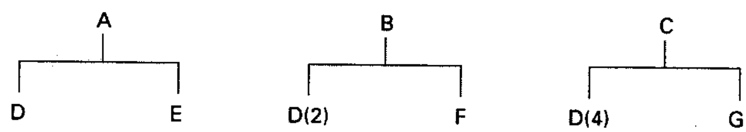
Quantity	Lead Time
1–200	1
201–550	2
551–999	3



7. Eighty units of end item X are needed at the beginning of week 6, and another 30 units are needed at the beginning of week 8. Prepare a material requirements plan for component D. D can only be ordered in whole cases (50 units per case). One case of D is automatically received every other week, beginning in week 1 (i.e., weeks 1, 3, 5, 7). Also, there are 30 units of B and 20 units of D now on hand. Lead times for all items are a function of quantity: one week for up to 100 units, two weeks for 101 to 200 units, three weeks for 201 to 300 units, and four weeks for 301 or more units.



8. Oh No!, Inc., sells three models of radar detector units. It buys the three basic models (E, F, and G) from a Japanese manufacturer and adds one, two, or four lights (component D) to further differentiate the models. D is bought from a domestic producer.



Lead times are one week for all items except C, which is two weeks. There are ample supplies of the basic units (E, F, and G) on hand. There are also 10 units of B, 10 units of C, and 25 units of D on hand. Lot-sizing rules are lot-for-lot ordering for all items except D, which must be ordered in multiples of 100 units. There is a scheduled receipt of 100 units of D in week 1.

The master schedule calls for 40 units of A to be produced in week 4, 60 units of B in week 5, and 30 units of C in week 6. Prepare a material requirements plan for D and its parents.

9. Assume that you are the manager of a shop that assembles power tools. You have just received an order for 50 chain saws, which are to be shipped at the start of week 8. Pertinent information on the saws is

Item	Lead Time (weeks)	On Hand	Components
Saw..........	2	15	A(2), B(1), C(3)
A............	1	10	E(3), D(1)
B............	2	5	D(2), F(3)
C............	2	30	E(2), D(2)
D............	1	20	
E............	1	10	
F............	2	30	

a. Develop a product structure tree, an assembly time chart, and a master schedule.
b. Develop the material requirements plan for component E using lot-for-lot ordering.
c. Suppose now that capacity to produce part E is limited to a maximum of 100 units per period. Revise the planned-order releases for periods 1–4 so that the maximum is not exceeded in any period, keeping in mind an objective of minimizing carrying costs. The quantities need not be equal in every period. Note that the gross requirements for E will remain the same. However, quantities in some of the other rows will change. Determine the new cell values for those rows.

10. Assume that you are the manager of Assembly, Inc. You have just received an order for 40 units of an industrial robot, which is to be delivered at the start of week 7 of your schedule. Using the following information, determine how many units of subassembly G to order and the timing of those

orders, given that subassembly G must be ordered in multiples of 80 units and all other components are ordered lot-for-lot. Assume that the components are used only for this particular robot.

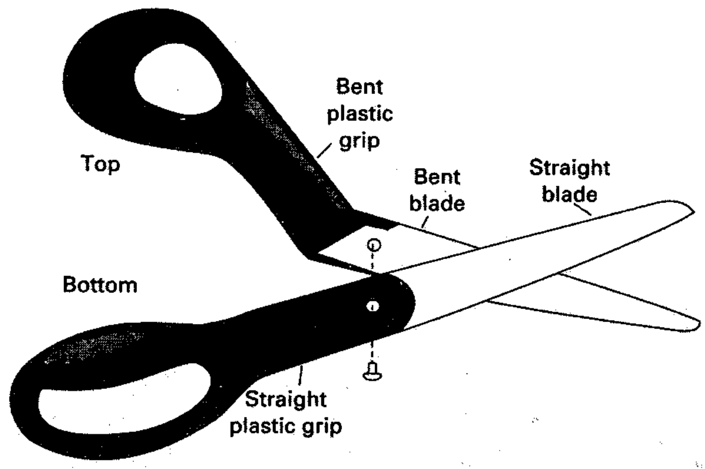
Item	Lead Time (weeks)	On Hand	Components
Robot	2	10	B, G, C(3)
B	1	5	E, F
C	1	20	G(2), H
E	2	4	—
F.............	3	8.	—
G	2	15	—
H	1	10	—

11. Determine material requirements plans for parts N and V and subassembly I as described in Solved Problem 2 for each of the following:
    a. Assume that there are currently 100 Ns on hand and scheduled receipts of 40 Is and 10 Vs at the beginning of week 3. No Es are on hand; 120 Es are needed at the start of week 5.
    b. Assume on-hand and scheduled receipts as in part *a.* Now suppose that 100 Es are needed at the start of week 5 and 50 at the start of week 7. Also, use multiples of these order sizes: N, 800; V, 200. Use lot-for-lot ordering for I.
    c. Using your answer to part *b,* update the MRP for V, using the following additional information for each of these cases: (1) one week has elapsed (making it the start of week 2), and (2) three weeks have elapsed (making it the start of week 4). *Note:* Start your revised plans so that the updated time in each case is designated as week 1.
    The updated master schedule now has an order for 100 units of E in week 8 of case 1 (i.e., week 9 under the former master schedule). Assume all orders are released and received as planned.
12. A firm that produces electric golf carts has just received an order for 200 carts, which must be ready for delivery at the start of week 8. Information concerning the product structure, lead times, and quantities on hand is shown in the following table. Use this information to do each of the following:
    a. Construct a product tree.
    b. Construct an assembly time chart.
    c. Develop a material requirements plan that will provide 200 golf carts by week 8 assuming lot-for-lot ordering.

Parts List for Electric Golf Cart	Lead Time	Quantity on Hand
Electric golf cart	1	0
Top......................	1	40
Base	1	20
Top		
Supports (4)	1	200
Cover....................	1	0
Base		
Motor	2	300
Body	3	50
Seats (2)	2	120
Body		
Frame	1	35
Controls	1	0
Wheel assemblies (4)......	1	240

efer to Problem 12. Assume that unusually mild weather has caused a change in the quantity and ng of orders for golf carts. The revised plan calls for 100 golf carts at the start of week 6, 100 at of week 8, and 100 at the start of week 9.
a master schedule for this revised plan.
the timing and quantities for orders for tops and bases.
quipment problems reduce the firm's capacity for assembling bases to 50 units per ur material plan for bases to reflect this, but still meet delivery dates.

14. Using the diagram below, do the following:
    a. Draw a tree diagram for the scissors.
    b. Prepare an MRP for scissors. Lead times are one day for each component and final scissor assembly, but two days for the plastic grips. Six hundred pairs of scissors are needed on Day 6. *Note:* There are 200 straight blades and 350 bent blades on hand, and 40 top blade assemblies on hand.



15. A company that manufactures paving material for driveways and parking lots expects the following demand for its product for the next four weeks:

Week number	1	2	3	4
Material (tons)	40	80	60	70

The company's labor and machine standards and available capacities are

	Labor	**Machine**
Production standard (hours per ton)	4	3
Weekly production capacity (hours)	300	200

a. Determine the capacity utilization for labor and machine for each of the four weeks.
b. In which weeks do you foresee a problem? What options would you suggest to resolve any problems? What costs are relevant in making a decision on choosing an option?

16. A company produces two very similar products that go through a three-step sequence of fabrication, assembly, and packaging. Each step requires one day for a lot to be completely processed and moved to the next department. Processing requirements for the departments (hours per unit) are

	FABRICATION		**ASSEMBLY**		**PACKAGING**	
Product	**Labor**	**Machine**	**Labor**	**Machine**	**Labor**	**Machine**
A	2	1	1.5	1	1	.5
B	1	1	1	1	1.5	.5

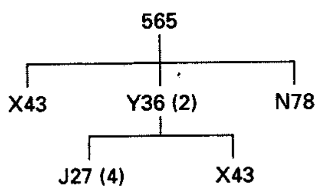
Department capacities are all 700 hours of labor and 500 hours of machine time, except Friday, when capacities are 200 hours for both labor and machine time. The following production schedule is for next week:

Day	**Mon**	**Tues**	**Wed**	**Thurs**	**Fri**
A	200	400	100	300	100
B	300	200	200	200	200

a. Develop a production schedule for each department that shows the capacity requirements for each product and the total load for each day. Ignore changeover time.
b. Evaluate the projected loading for the first three days of the week. Is the schedule feasible? What do you suggest for balancing the load?

17. The MRP Department has a problem. Its computer "died" just as it spit out the following information: Planned order release for item J27 = 640 units in week 2. The firm has been able to reconstruct all the information they lost except the master schedule for end item 565. The firm is fortunate because J27 is used only in 565s. Given the following product structure tree and associated inventory status record information, determine what master schedule entry for 565 was exploded into the material requirements plan that killed the computer.

Part Number	On Hand	Lot Size	Lead Time
565	0	Lot-for-lot	1 week
X43	60	120	1 week
N78	0	Lot-for-lot	2 weeks
Y36	200	Lot-for-lot	1 week
J27	0	Lot-for-lot	2 weeks



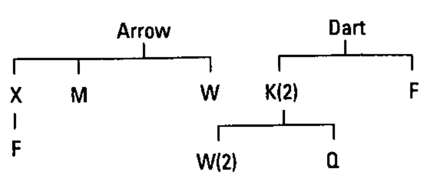
DMD Enterprises

CASE

After the "dot com" he tried to start folded, David "Marty" Dawkins decided to pursue his boyhood dream of owning a bike factory. After several false starts, he finally got the small company up and running. The company currently assembles two models Marty designed: the Arrow and the Dart. The company hasn't turned a profit yet, but Marty feels that once he resolves some of the problems he's having with inventory and scheduling, he can increase productivity and reduce costs.

At first, he ordered enough bike parts and subassemblies for four months' worth of production. Parts were stacked all over the place, seriously reducing work space and hampering movement of workers and materials. And no one knew exactly where anything was. In Marty's words, "It was a solid mess!"

He and his two partners eventually managed to work off most of the inventory. They hope to avoid similar problems in the future by using a more orderly approach. Marty's first priority is to develop an MRP plan for upcoming periods. He wants to assemble 15 Arrows and 10 Darts each week, for weeks 4 through 8. The product structure trees for the two bikes follow.



One of Marty's partners, Ann, has organized information on lead times, inventory on hand, and lot-sizing rules (established by suppliers):

Item	Lead Time (weeks)	On Hand	Lot-Sizing Rule
Arrow	2	5	Lot-for-lot
Dart	2	2	Lot-for-lot
X	1	5	$Q = 25$
W	2*	2	Multiples of 12
F	1	10	$Q = 30$
K	1	3	Lot-for-lot
Q	1	15	$Q = 30$
M	1	0	Lot-for-lot

*LT = 3 weeks for orders of 36 or more units on this item.

Scheduled receipts are

Period 1: 20 Arrows: 18 Ws

Period 2: 20 Darts: 15 Fs

As the third partner, it is your job to develop the material requirements plan.

Stickley Furniture

OPERATIONS TOUR

Introduction

www.stickley.com

L.&J.G. Stickley was founded in 1900 by brothers Leopold and George Stickley. Located just outside of Syracuse, New York, the company is a producer of fine cherry, white oak, and mahogany furniture. In the 1980s, the company reintroduced the company's original line of mission oak furniture, which now accounts for nearly 50 percent of the company's sales.

Over the years, the company experienced both good and bad times, and at one point, it employed over 200 people. But by the early 1970s, the business was in disarray; there were only about 20 full-time employees, and the company was on the brink of bankruptcy. The present owners bought the ailing firm in 1974, and under their leadership, the company has prospered and grown, and now has 1,350 employees. Stickley has five retail showrooms in New York State, two in Connecticut, one in North Carolina, and its furniture is sold nationally by some 120 dealers.

Production

The production facility is a large, rectangular building with a 30-foot ceiling. Furniture making is labor intensive, although saws, sanders, and other equipment are very much a part of the process. In fact, electric costs average about $60,000 a month. The company has its own tool room where cutting tools are sharpened, and replacement parts are produced as needed.

Worker skills range from low-skilled material handlers to highly skilled craftsmen. For example, seven master cabinet makers handle customized orders.

The process (see figure on pg. 613) begins with various sawing operations where large boards received from the lumber mills are cut into smaller sizes. The company recently purchased a computer-controlled "optimizer" saw that greatly improves sawing productivity, and eliminates some waste. Workers inspect and mark knot locations and other defects they find on each piece of lumber before feeding it into the saw. The computer then determines the optimal set of cuttings, given the location of knots and other defects, and standard lengths needed for subsequent operations. Approximately 20,000 board feet are cut each day. Subsequent sawing operations provide additional cuts for specific jobs.

Workers then glue some of the pieces together; they will end up as tops of tables, desks, dressers, or a similar item. Large presses hold 20 to 30 glued sections at a time. Other pieces that will become table or chair legs, chair backs or other items go through various shaping operations. Next comes a series of sanding operations, which remove excess glue from the glued sections, and smooth the surface of both glued pieces and other pieces.

Some of the pieces may require drilling or mortising, an operation in which rectangular holes and other shapes are cut into the wood. The company has a CNC (numerically controlled) router that can be programmed to make grooves and other specialty cuts. Some items require carving, which involves highly skilled workers.

Next, workers assemble the various components, either into subassemblies, or sometimes directly to other components to obtain completed pieces. Each item is stamped with the date of production, and components such as dresser drawers, cabinet doors, and expansion leaves of tables also are stamped to identify their location (e.g., top drawer, left door). Careful records are kept so that if a piece of furniture is ever returned for repairs,

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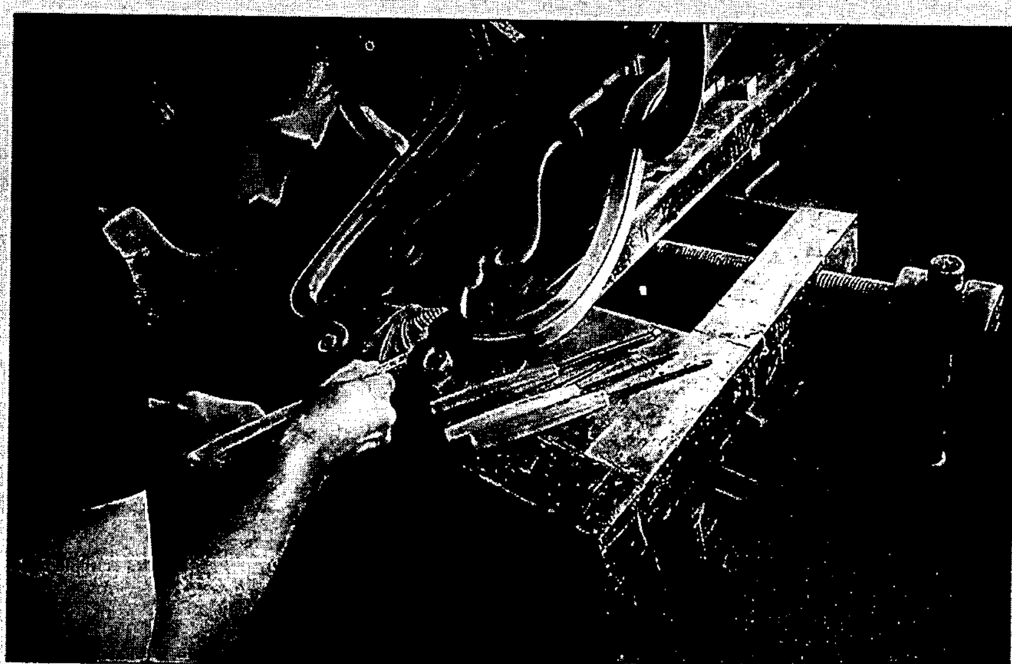

complete instructions are available (type of wood, finish, etc.) to enable repair people to closely match the original piece.

The furniture items then usually move to the "white inventory" (unfinished) section, and eventually to the finishing department where workers apply linseed oil or another finish before the items are moved to the finished goods inventory to await shipment to stores or customers.

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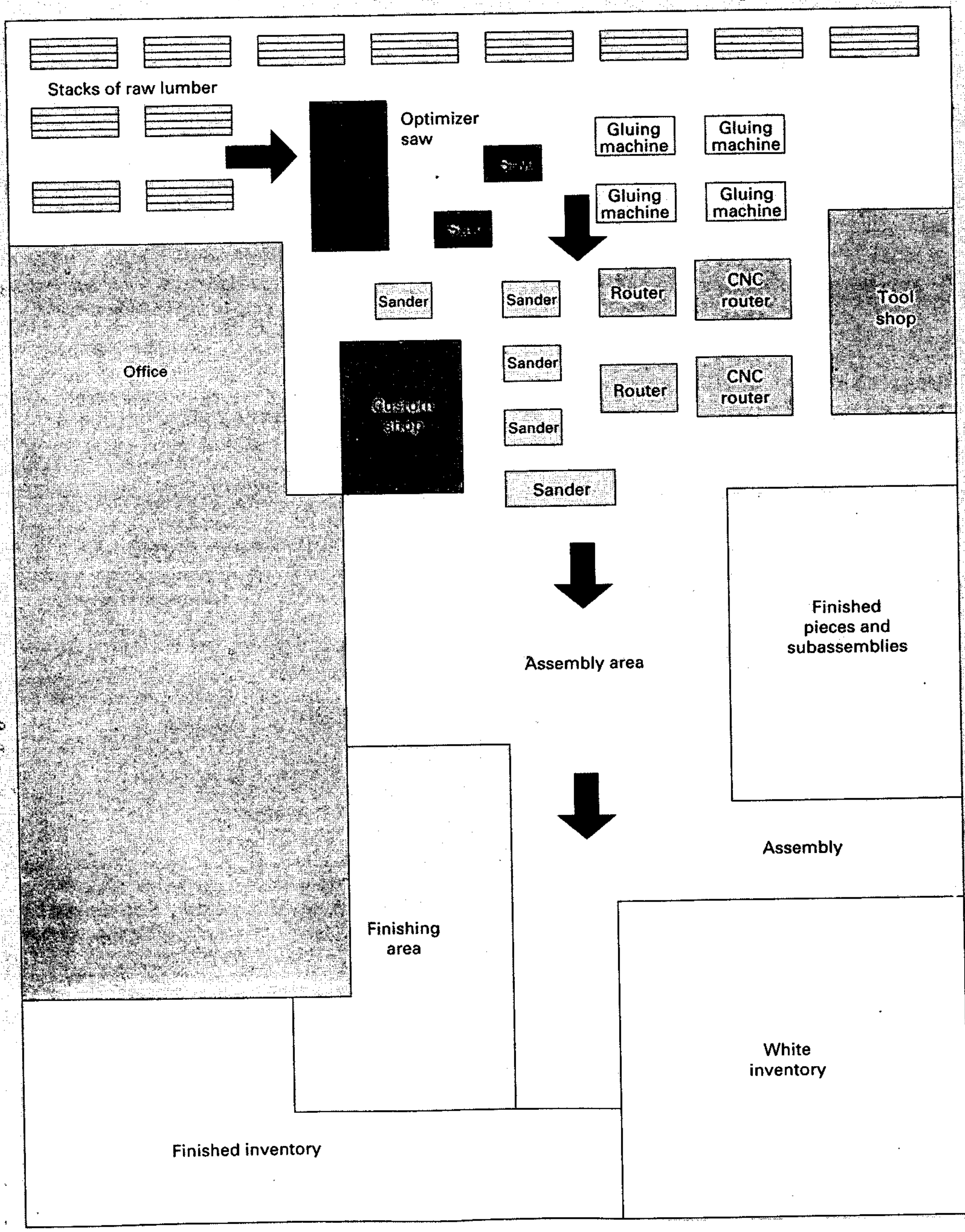

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Aggregate Planning

The company uses a level production plan (maintain steady output and steady labor force). Demand is seasonal; it is highest in the first and third quarters. During the second and fourth quarters, excess output goes into inventory; during the first and third quarters, excess demand is met using inventory. The production scheduler uses a schedule that is set for the next 8 to 10 weeks.

Production Control

Job sequence is determined by the amount of remaining inventory (days supply on hand), and processing time. Lot sizes are determined by factoring in demand, setup costs, and carrying costs. Typical lot sizes are 25 to 60 pieces. There are many jobs being done concurrently. Each job is accompanied by a set of bar codes that identify the job and the operation. As each operation is completed, the operator removes a bar code sticker and delivers it to the scheduling office where it is scanned into the computer, thereby enabling production control to keep track of progress on a job, and to know its location in the shop.

The company's policy of level output coupled with seasonal demand patterns means that prior to peak demand periods, excess output is used to build up inventories, which is then drawn down when demand exceeds production capacity during periods of peak production.

Inventory

In addition to the "white" inventory and a small finished goods inventory, the company maintains an inventory of furniture pieces (e.g., table and chair legs) and partially assembled items. This inventory serves two important functions. One is to reduce the amount of time needed to respond to customer orders rather than having to go through the entire production process to obtain needed items, and the other is that it helps to smooth production and utilize idle machinery/workers. Because of unequal job times on successive operations, some workstations invariably have slack time while others work at capacity. This is used to build an inventory of commonly used pieces and subassemblies. Moreover, because pieces are being made for inventory, there is flexibility in sequencing. This permits jobs that have similar setups to be produced in sequence, thereby reducing setup time and cost.

Quality

Each worker is responsible for checking his or her quality, as well as the quality of materials received from preceding operations, and to report any deficiencies. In addition, on several difficult operations, quality control people handle inspections and work with operators to correct any deficiencies. The company is considering a TQM approach, but has not yet made a decision on whether to go in that direction.

Questions

1. Which type of production processing—job shop, batch, repetitive, or continuous—is the primary mode of operation at Stickley Furniture? Why? What other type of processing is used to a lesser extent? Explain.
2. How does management keep track of job status and location during production?
3. Suppose the company has just received an order for 40 mission oak dining room sets. Briefly list the kinds of information the company will need to plan, schedule, and process this job.
4. What benefits, and what problems, would you expect, given the company's level production policy?
5. Can you suggest any changes that might be beneficial to the company? What are they?

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CHAPTER 14

JIT and Lean Operations

LEARNING OBJECTIVES

After completing this chapter, you should be able to:

1. Explain what is meant by the term *lean operations system.*
2. List each of the goals of JIT and explain its importance.
3. List and briefly describe the building blocks of JIT.
4. List the benefits of the JIT system.
5. Outline the considerations important in converting a traditional mode of operations to a JIT system.
6. List some of the obstacles that might be encountered when converting to a JIT system.

CHAPTER OUTLINE

We've all heard the phrase "time is money." More and more companies are taking this to heart, streamlining their operations using approaches such as just-in-time (JIT). The benefits of JIT operations can be extraordinary in both manufacturing and service. For example, in the service sector, Southwest Airlines has been quite successful using a JIT approach. Southwest focuses on having its planes spend as little time as possible on the ground between flights. Southwest began with a goal of getting time on the ground down to 18 minutes or less. That is, the time from when the plane lands and unloads passengers to the time it takes off after boarding new passengers. Using a JIT approach, that goal was achieved, and now it is striving for a turnaround time of 12 minutes or less. How was it accomplished? Persistence and attention to detail contributed. So did the fact that Southwest uses just one type of airplane, a Boeing 737. Because of this, pilot training, aircraft maintenance, cleaning, and flight preparation are all standardized, contributing not only to low turnaround time, but also to low costs. Southwest Airlines' approach is quite different from its competitors', but its low cost has been welcomed by the market, and helped to make it a profitable airline at a time when other major carriers are in, or considering, bankruptcy!

The term **just-in-time (JIT)** is used to refer to an operations system in which materials are moved through the system, and services are delivered with precise timing so that they are delivered at each step of the process just as they are needed—hence the name *just-in-time.* Initially, the term *JIT* referred to the movement of materials, parts, and semifinished goods within a production system. Over time, the scope of JIT broadened and the term became associated with *lean production.* Now the two terms are often used interchangeably to refer to a highly coordinated, repetitive manufacturing or service system designed to produce a high volume of output with fewer resources than more traditional repetitive systems, but with the ability to accommodate more variety than traditional systems.

just-in-time (JIT) A highly coordinated processing system in which goods move through the system, and services are performed, just as they are needed.

www.southwest.com

One aspect of JIT involves production planning and control, which makes JIT one of the two basic approaches to manufacturing planning and control; the other is material requirements planning. JIT is sometimes viewed as a system for repetitive production operations, while MRP is considered a system for batch production. However, they are sometimes applied to similar situations, but the two systems function somewhat differently. MRP systems are fairly complex, requiring extensive and detailed shop floor controls. JIT systems are much simpler, involving only minimal shop floor controls. Moreover, MRP relies on a computer-based component-*scheduling* system to trigger production and deliveries, whereas JIT relies on visual or audible signals to trigger production and deliveries. Also, JIT operates on a "pull" or demand basis whereby work is pulled from each step in the process to the next step when the next step has a demand for it, rather than pushed on to the next step when work is completed at the current step. The two approaches are compared in more detail later in the chapter.

This chapter describes the JIT/lean production approach, including the basic elements of these systems and what it takes to make them work effectively. It also points out the benefits of these systems and the potential obstacles that companies may encounter when they attempt to convert from a traditional system to a JIT/lean production system.

INTRODUCTION

www.toyota.com

The JIT approach was developed at the Toyota Motor Company of Japan by Taiichi Ohno (who eventually became vice president of manufacturing) and several of his colleagues. The development of JIT in Japan was probably influenced by Japan being a crowded country with few natural resources. Not surprisingly, the Japanese are very sensitive to waste and inefficiency. They regard scrap and rework as waste, and excess inventory as an evil because it takes up space and ties up resources.

"The Nuts and Bolts of Japan's Factories" by Urban Lehner provides a number of important insights on the just-in-time approach to manufacturing, and some reasons for the successes Japanese manufacturers have achieved.

The Nuts and Bolts of Japan's Factories — READING

Urban C. Lehner

"If American automobile king Henry Ford I were alive today, I am positive he would have done what we did with our Toyota production system."

—Taiichi Ohno

TOYOTA CITY, Japan—Groping to explain "how Japan does it," experts have made much of the close ties between business and government and of the loyalty of Japan's highly skilled workers to their employers. They've noted the fierce competitiveness of Japanese companies in their home market, the nation's high savings rate, even the relative scarcity of lawyers.

Doubtless these are among the pieces needed to solve the puzzle. But some management consultants who've studied how Japan makes such high-quality, competitively priced products say there's another piece often overlooked. The Japanese, they say, have proved themselves increasingly adroit at organizing and running manufacturing operations. Japanese managers may lack the MBAs or the ability to plot big-picture business strategy of their American counterparts. But they know how to run factories.

"There's a growing acceptance that Japanese success is based at least in part on the development of manufacturing techniques that often tend to outrun our own," says management consultant Rex Reid, head of A.T. Kearney's Toyota office.

One of the most interesting examples of Japanese production management skills is a concern quite familiar to Americans: Toyota Motor Co., the largest-selling foreign automaker in the U.S.

Believe in Their System

Toyota officials resist claiming that their way of building autos is better than anyone else's. They're somewhat embarrassed by the exuberant projections of Henry Ford's behavior essayed by their former chief production executive, Taiichi Ohno, in his 1978 book. But Toyota men clearly remain believers in what Mr. Ohno called "the Toyota production system."

For a first-hand look at the system, take a walk through the Tsutsumi plant here in Toyota City, a town of 280,000 in central

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Japan that's the site of 8 of Toyota's 10 factories. Over here, Muneo Nakahara, 26 years old and an 8-year Toyota veteran, is doing his job. With the help of an overhead crane that Mr. Nakahara controls from a hand-held device, he hoists auto engines onto a conveyor belt that will take them to be matched up with auto bodies.

Mr. Nakahara is lifting the engines onto the conveyor from a small flat-bed truck that has brought them from the engine plant. Only two trucks carrying just 12 engines apiece park at Mr. Nakahara's post at any given time, so every few minutes an empty truck drives back to the engine plant and a new one takes its place.

That's the first feature of the Toyota system: no inventories. Toyota's factories keep on hand only that amount of parts needed for immediate production, from a few minutes' worth up to a few hours' worth, depending on the part. When fresh parts are needed—and only when they're needed—they're delivered from other Toyota plants or from outside suppliers directly to the production line.

Outsiders who've seen Toyota in action often call this the "kanban system," *kanban* being the Japanese word for the piece of paper enclosed in clear plastic that accompanies each bin of parts. (When a worker on the line begins drawing from a new bin, he removes the kanban and routes it back to the supplier, for whom it serves as an order for a new bin of parts.) But Toyota officials say the pieces of paper are just tools. They call this inventory control aspect of their broader system the "just-in-time" system.

The same philosophy guides the meshing of operations within each plant. An assembly line that is building subcomponents makes just that number of subcomponents immediately needed at the next stage of production. When it's made enough, it's changed over to build some other kind of subcomponent for a while. Likewise, the final assembly line first builds one kind of car, then another, in small lots—only as much as called for in actual orders from Toyota's sales unit. Toyota engineers "average" and "level" production among the lines to coordinate output without building inventories. They compare auto assembly to rowing a boat: Everybody has to be pulling on the oars at the same rate.

"They concentrate very heavily on avoiding end-item and intermediate-item storage," says a Ford official in Detroit who's seen the system at work. "They throw out the whole concept of mass production."

The benefits are substantial. Toyota doesn't need space for inventory, people to handle and control inventory, or borrowed money to finance inventory. "It cuts costs in a lot of ways," says an official of Nissan Motor Co., Japan's second-largest automaker, which has adopted an inventory control system similar to its rival's in some plants.

Then there are the side benefits. Because Toyota is constantly changing over its machines to make new things, its workers have become fast at repair and changeover. In his book, Mr. Ohno cites a mold on a press that initially took two to three hours to change. Today "it takes only three minutes to change the mold," Mr. Ohno says.

Aside from its emphasis on holding down inventories, Toyota's system stresses quality controls. Throughout the Tsutsumi plant are boards with electric lights to indicate conditions on each assembly line. A red light means a line has been stopped because of a problem. Every worker has a button or cord with which he can stop the line, and he's told to use it whenever he thinks something's wrong with the operation of the line or when he spots defects in the product.

"We lose production temporarily this way," concedes Fujio Cho, manager of the production control department at Toyota's headquarters. "But in our experience stopping lines helps us detect problems early and avoid bad practices."

Another feature that becomes clear is the company's penchant for training workers to do more than one job. The man who runs one machine switches off every few moments to run another. The man who feeds rear windows to a robot also "tags" car shells with instructions telling workers farther down the line what to install in them. This versatility allows Toyota to realign its work force more efficiently when business is bad.

Indeed, "recession" thinking underlies a big part of Toyota's system. Much of the system originated in the late 1940s and early 1950s, when Toyota was producing exclusively for a domestic market that wasn't very strong. The company has been operating on the conventional assumption that it's most efficient to produce in large lots, "but that kind of thinking has pushed us close to bankruptcy, because the large lots we were producing couldn't be sold," says Mr. Cho. Toyota couldn't lay off workers—Japan's a "life-time" employment system—so Toyota executives hit upon the simple yet radical idea that still pervades its operations: Overproduction is waste.

Source: "The Nuts and Bolts of Japan's Factories" by Urban C. Lehner, *The Wall Street Journal*, 1981.

In some respects, the just-in-time concept was operational over sixty years ago at Henry Ford's great industrial complex in River Rouge, Michigan.

In the mid 1920s, the Ford assembly plant in River Rouge, Michigan, was a state of the art industrial complex employing over 75,000 workers. In 1982, Eiji Toyoda, head of the Toyota Company toasted Ford's then president, Philip Caldwell, saying, "There is no secret to how we learned to do what we do—we learned it at the Rouge."

Toyota learned a great deal from studying Ford's operations and based its JIT approach on what it saw. However, Toyota was able to accomplish something that Ford couldn't: a system that could handle variety.

A widely held view of JIT is that it is simply a system for scheduling production that results in low levels of work-in-process and inventory. But in its truest sense, JIT represents a *philosophy* that encompasses every aspect of the process, from design to after the sale of a product. The philosophy is to pursue a system that functions well with minimal levels of inventories, minimal waste, minimal space, and minimal transactions. Truly, a *lean* system. As such, it must be a system that is not prone to disruptions and is flexible in terms of the product variety and range of volume that it can handle.

In the early days of JIT, JIT was simply a collection of methods and slogans (romantic JIT) rather than an actual system. Failure to recognize this caused some users to be disappointed with the results they were able to achieve.

Romantic JIT and Pragmatic JIT

READING

There are two views of JIT presented in the literature. Paul Zipkin refers to these views as *romantic* JIT and *pragmatic* JIT. Romantic JIT consists of various slogans and idealistic goals such as lot sizes of one, zero inventories, and zero defects. JIT is seen as a "revolution" for manufacturing, one that is relatively simple to install and maintain, and one that can lead to dramatic reductions in work-in-process (WIP) inventory and competitive advantage. Pragmatic JIT, on the other hand, consists of a collection of techniques, some fairly technical, that relate to machine changeovers, layout design, product simplification, quality training, equipment maintenance, and so on.

One problem with romantic JIT is that it is apt to appeal to senior managers, who are not much involved in the day-to-day operations on the shop floor level. They are attracted by the promise of inventory reductions and higher quality. They envision JIT as a quick fix to their problems, and look forward to lower WIP levels and increased inventory turnovers, which will lead to decreased inventory investment and improved cash flow. Thinking that JIT is a relatively simple concept, they expect that lower-level managers and workers will quickly and easily convert to this new way of thinking and soon achieve results, not comprehending the complexity that is involved, or the time they will need to achieve meaningful results. For example, it took Toyota over 20 years to perfect its JIT system!

Adopting the romantic view of JIT can lead to much frustration and disappointment as people on the shop floor struggle to achieve what senior management perceives to be relatively easy. Moreover, cutting back WIP inventories without dealing with the reasons for WIP can quickly lead to chaos on the shop floor, with delays and missed deliveries.

Source: Based on "Does Manufacturing Need a JIT Revolution" by Paul Zipkin, "Does Manufacturing Need a JIT Revolution?" *Harvard Business Review,* January–February 1991, pp. 40–50.

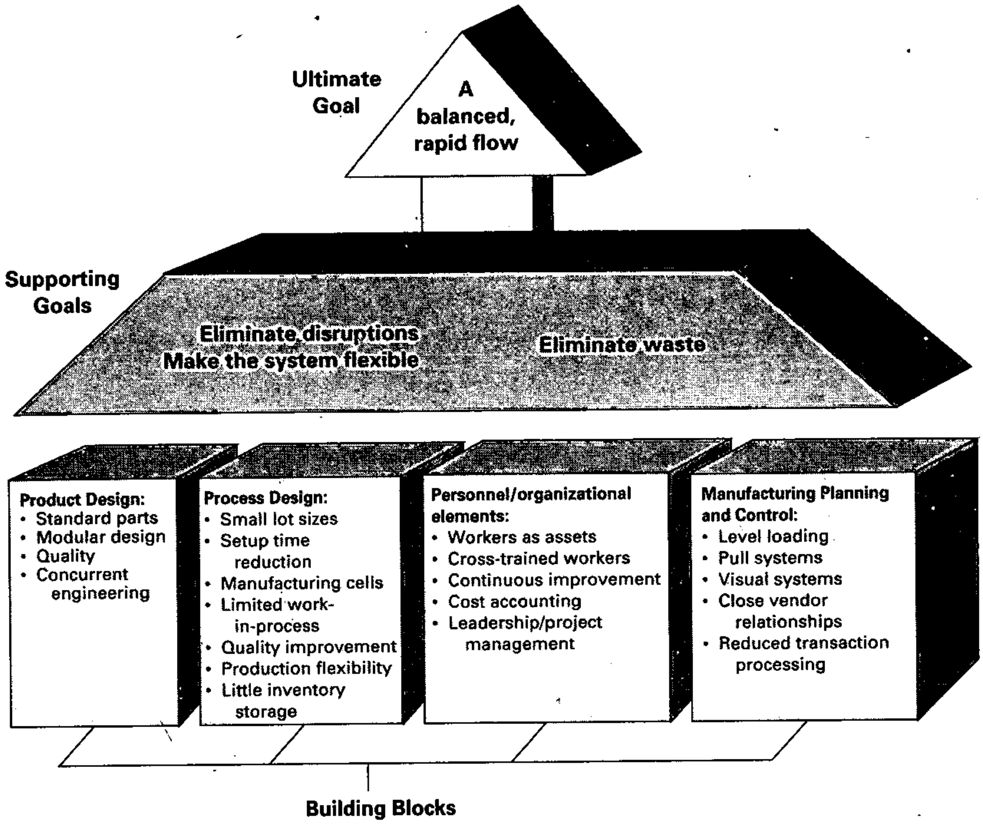


FIGURE 14.1

An overview of the goals and building blocks of lean systems

Source: Adapted from Thomas E. Vollmann, William L. Berry, and D. Clay Whybark. *Manufacturing Planning and Control Systems*, 3rd ed. Copyright 1992 Irwin/McGraw-Hill Companies, Inc. Used with permission.

In lean systems, quality is ingrained in both the product and the process. Companies that use lean operations have achieved a level of quality that enables them to function with small batch sizes and tight schedules. Lean systems have high reliability; major sources of inefficiency and disruption have been eliminated, and workers have been trained not only to function in the system but also to continuously improve it.

You'll get a better understanding of lean operations as you read about its goals and building blocks. Figure 14.1 provides an overview of the goals and building blocks.

SUPPORTING GOALS

The ultimate goal of JIT is a *balanced* system, that is, one that achieves a smooth, rapid flow of materials and/or work through the system. The idea is to make the process time as short as possible by using resources in the best possible way. The degree to which the overall goal is achieved depends on how well certain supporting goals are achieved. Those goals are

1. Eliminate disruptions.
2. Make the system flexible.
3. Eliminate waste, especially excess inventory.

Disruptions have a negative influence on the system by upsetting the smooth flow of products through the system, and they should be eliminated. Disruptions are caused by a variety of factors, such as poor quality, equipment breakdowns, changes to the schedule, and late deliveries. All these should be eliminated as much as possible. This will reduce the uncertainty that the system must deal with.

A *flexible system* is one that is robust enough to handle a mix of products, often on a daily basis, and to handle changes in the level of output while still maintaining balance and throughput speed. This enables the system to deal with some uncertainty. Long setup times and long lead times negatively impact the flexibility of the system. Hence, reduction of setup and lead times is very important in a JIT system.

Waste represents unproductive resources; eliminating waste can free up resources and enhance production. *Inventory* is an idle resource, taking up space and adding cost to the system. It should be minimized as much as possible. In the JIT philosophy, other wastes include

a. *Overproduction*—involves excessive use of manufacturing resources.
b. *Waiting time*—requires space, adds no value.
c. *Unnecessary transporting*—increases handling, increases work-in-process inventory.
d. *Processing waste*—makes unnecessary production steps, scrap.
e. *Inefficient work methods*—reduce productivity, increase scrap, increase work-in-process inventory.
f. *Product defects*—require rework costs and possible lost sales due to customer dissatisfaction.

The existence of these wastes is an indication that improvement is possible. The list of wastes also can identify potential targets for continuous improvement efforts.

Sometimes the terms *big JIT* and *little JIT* are used to differentiate attempts to eliminate waste in operations. Big JIT focuses on vendor relationships, human relations, technology management, and materials and inventory management. Little JIT is more narrowly focused on scheduling materials and services for operations.

BUILDING BLOCKS

The design and operation of a JIT system provide the foundation for accomplishing the aforementioned goals. As shown in Figure 14.1, the building blocks are:

1. Product design
2. Process design
3. Personnel/organizational elements
4. Manufacturing planning and control

Speed and simplicity are two common threads that run through these building blocks.

Product Design

Four elements of product design are important for JIT:

1. Standard parts.
2. Modular design.
3. Highly capable production systems with quality built in.
4. Concurrent engineering.

The first two elements relate to speed and simplicity.

The use of *standard parts* means that workers have fewer parts to deal with, and training times and costs are reduced. Purchasing, handling, and checking quality are more routine and lend themselves to continual improvement. Another important benefit is the ability to use standard processing.

Modular design is an extension of standard parts. Modules are clusters of parts treated as a single unit. This greatly reduces the number of parts to deal with, simplifying assembly, purchasing, handling, training, and so on. Standardization has the added benefit of reducing the number of different parts contained in the bill of materials for various products, thereby simplifying the bill of materials.

JIT requires highly capable production systems. Quality is the *sine qua non* ("without which not") of JIT. It is crucial to JIT systems because poor quality can create major disruptions. Quality must be embedded in goods and processes. The systems are geared to a smooth flow of work; the occurrence of problems due to poor quality creates disruption in this flow. Because of small lot sizes and the absence of buffer stock, production must cease when problems occur, and it cannot resume until the problems have been resolved. Obviously, shutting down an entire process is costly and cuts into planned output levels, so it becomes imperative to try to avoid shutdowns, and to quickly resolve problems when they do appear.

JIT systems use a comprehensive approach to quality. Quality is designed into the product and the production process. High quality levels can occur because JIT systems produce standardized products that lead to standardized job methods, employ workers who are very familiar with their jobs, and use standardized equipment. Moreover, the cost of product design quality (i.e., building quality in at the *design* stage) can be spread over many units, yielding a low cost per unit. It is also important to choose appropriate quality levels in terms of the final customer and of manufacturing capability. Thus, product design and process design must go hand in hand.

Engineering changes can be very disruptive to smooth operations. Concurrent engineering practices (described in Chapter 4) can substantially reduce these disruptions.

Process Design

Seven aspects of process design are particularly important for JIT systems:

1. Small lot sizes
2. Setup time reduction
3. Manufacturing cells
4. Limited work in process
5. Quality improvement
6. Production flexibility
7. Little inventory storage

Small Lot Sizes In the JIT philosophy, the ideal lot size is one unit, a quantity that may not always be realistic owing to practical considerations requiring minimum lot sizes (e.g., machines that process multiple items simultaneously, heat-treating equipment that processes multiple items simultaneously, and machines with very long setup times). Nevertheless, the goal is still to reduce the lot size as much as possible. Small lot sizes in both the production process and deliveries from suppliers yield a number of benefits that enable JIT systems to operate effectively. First, with small lots moving through the system, in-process inventory is considerably less than it is with large lots. This reduces carrying costs, space requirements, and clutter in the workplace. Second, inspection and rework costs are less when problems with quality occur, because there are fewer items in a lot to inspect and rework.

Small lots also permit greater flexibility in scheduling. Repetitive systems typically produce a small variety of products. In traditional systems, this usually means long production runs of each product, one after the other. Although this spreads the setup cost for a run over many items, it also results in long cycles over the entire range of products. For instance, suppose a firm has three product versions, A, B, and C. In a traditional system, there would be a long run of version A (e.g., covering two or three days or more), then a long run of version B, followed by a long run of version C before the sequence would repeat. In contrast, a JIT system, using small lots, would frequently shift from producing A to producing B and C. This flexibility enables JIT systems to respond more quickly to changing customer demands for output: JIT systems can produce just what is needed, when it is needed. The contrast between small and large lot sizes is illustrated in Figure 14.2. A summary of the benefits of small lot sizes is presented in Table 14.1.

A = units of product A
B = units of product B
C = units of product C

JIT approach

AAA BBBBBBB CC AAA BBBBBBB CC AAA BBBBBBB CC AAA BBBBBBB CC

Time →

Large-lot approach

AAAAAAAAAAAA BBBBBBBBBBBBBBBBBBBBBBBBB CCCCCCCCC AAAAAAAAAAA

Time →

FIGURE 14.2

JIT versus large-lot run sizes

TABLE 14.1
Benefits of small lot sizes

Reduces inventory, lowers carrying costs
Less space required to store inventory
Less rework if defects occur
Less inventory to "work off" before implementing product improvements
Problems are more apparent
Increases production flexibility
Easier to balance operations

It is important to note that the use of small lot sizes is not in conflict with the EOQ approach. The fact is that two aspects of the JIT philosophy support small EOQ lot sizes. One is that inventory holding cost is deemed to be high, but because this cost is based on the average inventory, inventory costs can be lowered by reducing the lot size, which reduces average inventory. Second, there is emphasis on reducing the setup cost. Thus, both higher holding costs and lower setup costs act to reduce the optimal lot size.

www.generalmills.com

Setup Time Reduction Small lots and changing product mixes require frequent setups. Unless these are quick and relatively inexpensive, the time and cost to accomplish them can be prohibitive. Moreover, long setup times require holding more inventory than with short setup times. Hence, there is strong emphasis on reducing setup times. In JIT, workers are often trained to do their own setups. Moreover, programs to reduce setup time and cost are used to achieve the desired results; a deliberate effort is required, and workers are usually a valuable part of the process.

General Mills Turns to NASCAR to Reduce Changeover Time

NEWSCLIP

Karen Mills

MINNEAPOLIS—When General Mills wanted to cut the time it takes to make a product changeover at a Betty Crocker plant, it turned to NASCAR for help. The food company sent a team to work with a Winston Cup pit crew "because nobody can change over a car faster than these guys can," said Randy Darcy, senior vice president of General Mills' supply chain operations.

After studying the NASCAR crew, General Mills cut to 12 minutes—from as long as 4½ hours—the time it takes to switch production lines from one Betty Crocker meal to another. One thing the mechanics learned from working with the NASCAR pit crew was to videotape each of the changeovers, then critique everything that happened.

Setup tools and equipment and setup procedures must be simple and standardized. Multipurpose equipment or attachments can help to reduce setup time. For instance, a machine with multiple spindles that can easily be rotated into place for different job requirements can drastically reduce job changeover time. Moreover, *group technology* (described in Chapter 6) may be used to reduce setup cost and time by capitalizing on similarities in recurring operations. For instance, parts that are similar in shape, materials, and so on, may require very similar setups. Processing them in sequence on the same equipment can reduce the need to completely change a setup; only minor adjustment may be necessary.

www.ford.com

More than sixty years have passed since the introduction of Henry Ford's Model A with its all-steel body. Yet, across the world, nearly all motor-vehicle bodies are still produced by welding together about 300 metal parts stamped from sheet steel.

Auto makers have produced these "stampings" by employing one of two different methods. A few tiny craft producers, such as Aston Martin, cut sheets of metal—usually aluminum—to a gross shape, then beat these blanks by hand on a die to their final shape. (A die is simply a hard piece of metal in the precise shape the sheet metal should assume under pounding.)

Any producer making more than a few hundred cars a year—a category that includes auto makers ranging from Porsche to General Motors—starts with a large roll of sheet steel. They run this sheet through an automated "blanking" press to produce a stack of flat blanks slightly larger than the final part they want. They then insert the blanks in massive stamping presses containing matched upper and lower dies. When these dies are pushed together under thousands of pounds of pressure, the two-dimensional blank takes the three-dimensional shape of a car fender or a truck door as it moves through a series of presses.

The problem with this second method, from Ohno's perspective, was the minimum scale required for economical operation. The massive and expensive Western press lines were designed to operate at about twelve strokes per minute, three shifts a day, to make a million or more of a given part in a year. Yet, in the early days, Toyota's entire production was a few thousand vehicles a year.

The dies could be changed so that the same press line could make many parts, but doing so presented major difficulties. The dies weighed many tons each, and workers had to align them in the press with absolute precision. A slight misalignment produced wrinkled parts. A more serious misalignment could produce a nightmare in which the sheet metal melted in the die, necessitating extremely expensive and time-consuming repairs.

To avoid these problems, [Western manufacturers] assigned die changes to specialists. Die changes were undertaken methodically and typically required a full day to go from the last part with the old dies to the first acceptable part from the new dies. As volume in the Western industry soared after World War II, the industry found an even better solution to the die-change problem. Manufacturers found they often could "dedicate" a set of presses to a specific part and stamp these parts for months, or even years, without changing dies.

To Ohno, however, this solution was no solution at all. The dominant Western practice required hundreds of stamping presses to make all the parts in car and truck bodies, while Ohno's capital budget dictated that practically the entire car be stamped from a few press lines.

His idea was to develop simple die-change techniques and to change dies frequently—every two to three hours versus two to three months—using rollers to move dies in and out of position and simple adjustment mechanisms. Because the new techniques were easy to master and production workers were idle during the die changes, Ohno hit upon the idea of letting the production workers perform the die changes as well.

By purchasing a few used American presses and endlessly experimenting from the late 1940s onward, Ohno eventually perfected his technique for quick changes. By the late 1950s, he had reduced the time required to change dies from a day to an astonishing three minutes and eliminated the need for die-change specialists. In the process, he made an unexpected discovery—it actually cost less per part to make small batches of stampings than to run off enormous lots.

There were two reasons for this phenomenon. Making small batches eliminated the carrying cost of the huge inventories of finished parts that mass-production systems required. Even more important, making only a few parts before assembling them into a car caused stamping mistakes to show up almost instantly.

The consequences of this latter discovery were enormous. It made those in the stamping shop much more concerned about quality, and it eliminated the waste of large numbers of defective parts—which had to be repaired at great expense, or even discarded—that were discovered only long after manufacture. But to make this system work at all—a system that ideally produced two hours or less of inventory—Ohno needed both an extremely skilled and a highly motivated work force.

If workers failed to anticipate problems before they occurred and didn't take the initiative to devise solutions, the work of the whole factory could easily come to a halt. Holding back knowledge and effort—repeatedly noted by industrial sociologists as a salient feature of all mass-production systems—would swiftly lead to disaster in Ohno's factory.[1]

Manufacturing Cells One characteristic of many JIT systems is multiple *manufacturing cells.* The cells contain the machines and tools needed to process families of parts having similar processing requirements. In essence, the cells are highly specialized and efficient production centers. Among the important benefits of manufacturing cells are reduced changeover times, high utilization of equipment, and ease of cross-training operators. The combination of high cell efficiency and small lot sizes results in very *little work-in-process inventory.*

[1]Excerpt reprinted with permission of Scribner, an imprint of Simon & Schuster Adult Publishing Group, from pp. 51–53 of, *The Machine That Changed the World,* by James P. Womack, Daniel T. Jones, and Daniel Roos. © 1990 by James P. Womack, Daniel T. Jones, Daniel Roos, and Donna Sammons Carpenter.

TABLE 14.2
Guidelines for increasing production flexibility

1. Reduce downtime due to changeovers by reducing changeover time.
2. Use preventive maintenance on key equipment to reduce breakdowns and downtime.
3. Cross-train workers so they can help when bottlenecks occur or other workers are absent. Train workers to handle equipment adjustments and minor repairs.
4. Use many small units of capacity; many small cells make it easier to shift capacity temporarily and to add or subtract capacity than a few units of large capacity.
5. Use off-line buffers. Store infrequently used safety stock away from the production area to decrease congestion and to avoid continually turning it over.
6. Reserve capacity for important customers.

Source: Adapted from Edward M. Knod Jr. and Richard J. Schonberger, *Operations Management: Meeting Customers' Demands,* 7th ed. (New York: McGraw-Hill, 2001).

Quality Improvement The occurrence of quality defects during the process can disrupt the orderly flow of work. Consequently, problem solving is important when defects occur. Moreover, there is a never-ending quest for *quality improvement,* which often focuses on finding and eliminating the causes of problems so they do not continually crop up.

autonomation Automatic detection of defects during production.

jidoka Japanese term for autonomation.

JIT systems sometimes minimize defects through the use of **autonomation** (note the extra syllable *on* in the middle of the word). Also referred to as **jidoka,** it involves the automatic detection of defects during production. It can be used with machines or manual operations. It consists of two mechanisms: one for detecting defects when they occur and another for stopping production to correct the cause of the defects. Thus, the halting of production forces immediate attention to the problem, after which an investigation of the problem is conducted, and corrective action is taken to resolve the problem.

Production Flexibility The overall goal of a JIT system is to achieve the ability to process a mix of products in a smooth flow. One potential obstacle to this goal is bottlenecks that occur when portions of the system become overloaded. The existence of bottlenecks reflects inflexibilities in a system. Process design can increase *production flexibility* and reduce bottlenecks in a variety of ways. Table 14.2 lists some of the techniques used for this purpose.

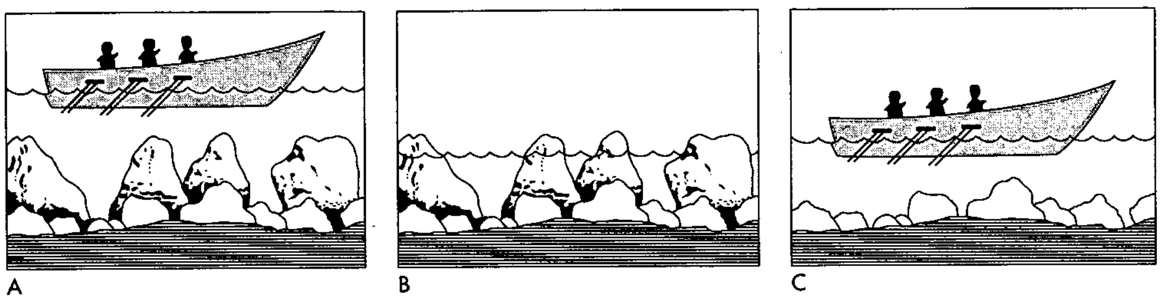
Inventory Storage JIT systems are designed to *minimize* inventory storage. Recall that in the JIT philosophy, inventory storage is a waste. Inventories are buffers that tend to cover up recurring problems that are never resolved, partly because they aren't obvious and partly because the presence of inventory makes them seem less serious. When a machine breaks down, it won't disrupt the system if there is a sufficient inventory of the machine's output to feed into the next workstation. The use of inventory as the "solution" can lead to increasing amounts of inventory if breakdowns increase. A better solution is to investigate the *causes* of machine breakdowns and focus on eliminating them. Similar problems with quality, unreliable vendors, and scheduling also can be solved by having ample inventories to fall back on. However, carrying all that extra inventory creates a tremendous burden in cost and space and allows problems to go unresolved.

The JIT approach is to pare down inventories gradually in order to uncover the problems. Once they are uncovered and solved, the system removes more inventory, finds and solves additional problems, and so on. A useful analogy is a boat on a pond that has large, hidden rocks. (See Figure 14.3.) The rocks represent problems that can hinder production (the boat). The water in the pond that covers the rocks is the inventory in the system. As the water level is slowly lowered, the largest rocks are the first to appear (those problems are the first to be identified). At that point, efforts are undertaken to remove these rocks from the water (resolve these problems). Once that has been accomplished, additional water is removed from the pond, revealing the next layer of rocks, which are then worked on. As more rocks are removed, the need for water to cover them diminishes. Likewise, as more of the major production problems are solved, there is less need to rely on inventory or other buffers.

Low inventories are the result of a *process* of successful problem solving, one that has occurred over time. Furthermore, because it is unlikely that all problems will be found and resolved, it is necessary to be able to deal quickly with problems when they do occur. Hence,

FIGURE 14.3

Large rocks (problems) are hidden by a high water level (inventory) in A. Lower water level (B) reveals rocks (problems such as bottlenecks, waste, poor timing). Once the large rocks are removed, the water level (inventory) can be lowered (C).



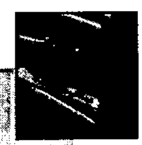
there is a continuing need to identify and solve problems within a short time span to prevent new problems from disrupting the smooth flow of work through the system.

One way to minimize inventory storage in a JIT system is to have deliveries from suppliers go directly to the production floor, which completely eliminates the need to store incoming parts and materials. At the other end of the process, completed units are shipped out as soon as they are ready, which minimizes storage of finished goods. Coupled with low work-in-process inventory, these features result in systems that operate with very little inventory.

Among the advantages of lower inventory are less carrying cost, less space needed, less tendency to rely on buffers, less rework if defects occur, and less need to "work off" current inventory before implementing design improvements. But carrying less inventory also has some risks: The primary one is that if problems arise, there is no safety net. Another is missed opportunities if the system is unable to respond quickly to them.

Pedal Pushers

READING



Tim Stevens

Green Gear Cycling adopts big-company, lean-manufacturing principles to produce custom bikes

Across the street from the Fred Meyer store, behind a NAPA Auto Parts outlet in Eugene, Oregon, lies one of those gems you'd surely miss if you weren't looking for it. It's Green Gear Cycling Inc., manufacturer of Bike Friday, the largest-selling custom-made folding bike in the world. The bike fits into a car trunk, a tight storage space, or an optional suitcase to travel on a plane like regular baggage. (The suitcase even can be converted into a trailer to haul gear.) "Like Robinson Crusoe's man Friday, the Bike Friday is always there when you need it," says Alan Scholz, CEO.

Green Gear's operations are as distinctive as its product. A relatively small company ($3 million in sales, 30 employees, 17,000 sq. ft. of production space), Green Gear uses advanced manufacturing principles—adopted from Toyota Motor Corp. and others normally associated with considerably larger facilities. Management is split between Alan Scholz, who handles the business side, and his younger brother Hanz, product design and development manager.

Because of the uniqueness of its products, the company is able to command a premium price for them, and customers pay in advance. "It's not unusual for someone to call us with plane ticket in hand and say they are going on a trip, [and] can we have a bike ready for them in so many days," says Alan Scholz. "We can accommodate those kinds of requests, from decision-to-buy to riding in three days. Most bike manufacturers have terrible margins and huge leadtimes. They have no levers. We give people what they want, when they want it. If you do that, people are willing to pay you for it."

This year the company will build about 2,000 bikes to customer weight, measurements, and equipment specifications, at an average selling price of $1,700 including the optional case. Twenty-five percent of sales are to overseas customers, primarily in Japan, the UK, Australia, and Europe. On the list of Bike Friday riders are a nuclear weapons inspector who ordered a cycle specifically for his assignment in Iraq; David Robinson, former center for the NBA's San Antonio Spurs; comedian Dick Smothers; Tour de France winner Greg LeMond; and a woman who is only 52 in. tall, demonstrating the range of vehicles produced. Bike Friday can be offered about 2.5 million different

(continued)

(concluded)

ways depending on size, components, and color. Folding, custom-made recumbent and tandem bikes also are available.

Build-to-Order Basics

Built individually, each Green Gear cycle begins its life as a bundle of tubes, components, and other structures. These are processed through a build-to-order, flow-manufacturing configuration that is organized in a series of cells, a production system the company deployed from the very start. "If you are a batch manufacturer, it's like pulling teeth to get lean and build in production cells," says Scholz. "If you start off that way, the people you hire just think that's the way it's done."

In the first cell, a U-shaped configuration, an operator works multiple pieces of dedicated equipment, all set to run automatically so that he can multitask. Here tubing is cut and shaped into frame members before moving to a welding cell. The cells are designed so that any one cell can do some of the work of the previous or next cell if production runs behind or ahead.

"It works like a track relay with a transition area," says Hanz Scholz. "We've set up everything with single-process–specific tools so there is no process changeover time, which is part of the Toyota Production System (TPS)." The flow motto is "touch it once, do it now." Once work on a bike has begun, it flows through the process without hesitation at any point.

Takt time, the time between completion of bikes at the end of the process, is adjusted based on how sales are going—another TPS concept based on producing to demand, not projection. "We look at sales velocity and set the takt time to deliver units at that rate," says Hanz Scholz. In May of this year the rate averaged one bike every 1.5 hours across the mix of different models (it takes about nine hours to build one bike). When a 50-bike order came in from a Japanese distributor, however, takt time was slashed to 27 minutes. Task-time reductions typically are accomplished with personnel from sales, service, and management departments supplemented with temps brought in to assist production.

Operating in a one-at-a-time flow system rather than in batches maximizes the chances for continuous improvement, according to Alan Scholz, who applies kaizen principles of continuous improvement to each bike. "For us, every bike is a batch, so we have 150 to 200 chances per month to make process improvements. A small manufacturer operating in a large-batch mode can be put out of business if he ruins just one. If you can make improvements as you find them, you can survive as a small manufacturer." When a quality problem is discovered, the operator switches on a red light and all procedures stop until the production cell is adjusted to eliminate the problem.

Stocking parts to cover the many variations of the bicycle would be far too costly for the company so, in lean-manufacturing style, inventory is handled kanban fashion, with parts reordered as they are used and minimum buffer stocks maintained based on vendor response time. Parts are pulled one bike at a time, three days before the ship date established by the customer, "just like Dell," says Scholz. "In fact the only difference between us and Dell is that you can't design a Bike Friday on the Internet . . . yet." (Michael Dell's wife Susan is a Bike Friday owner.)

"What's unique is that a company our size is handling inventory this way," says Scholz. "Many small companies feel it is too risky to operate like this, but we are proof that it can be successful." The kanban system replenishes inventory a little more often, "but it's a system that doesn't just order parts, it orders the right parts." Replenishing often so the company can operate at low inventory levels is an integral part of the cash-flow management expertise that helps make the company a success.

The company is in the process of moving to a "perpetual inventory" system that is expected to save thousands of dollars more in inventory. Parts will be reordered based on bikes sold, much as Kmart reorders based on sales rung at the cash register. "It's based on an MRP-type system, but without a lot of the things MRP requires," says Scholz. "Again, small companies tend not to have MRP because it costs too much." Green Gear's IS person is creating a system, based on a Microsoft Access database, to allow sales to "talk" to production. "The way it talks to production is through inventory. We'll be replacing inventory with information," Scholz notes.

Customers for Life

Lessons from Green Gear's success with lean manufacturing are applied to customer service and sales as well. Each sales consultant sits at a highly customized computer workstation, but with no desk. "That way it can't get cluttered up," says Hanz Scholz, "and for whatever they are doing, it encourages the 'touch it once, do it now' philosophy." Formerly housed in walled offices, the sales force now works in an open-office area. "If you have walls, you have barriers to the learning process," he adds. "Since we made the move, a lot of the fluctuations disappeared. Now all are selling in a similar way." And, since the change in September, sales are up 50%.

Green Gear practices a "Customers for Life" strategy it adopted from a luxury car dealer in Dallas. The dealer figured a customer that bought exclusively from him would spend in the neighborhood of $300,000 over his or her lifetime. "So," says Alan Scholz, "why nit-pick a $10 part?" A study of Bike Friday customers who have owned their bikes for more than three years shows there were repeat buys for other family members, adding a mountain bike or recumbent to the original "road" purchase, or upgrading to new technology. The company predicts a value of $10,000 to $25,000 for a lifetime customer. Therefore, it provides extra service at no cost when a bike comes in for repairs, or replaces a tire for free.

Source: Excerpted from Tim Stevens, "Pedal Pushers," *Industry Week*, July 17, 2000.

Personnel/Organizational Elements

There are five elements of personnel and organization that are particularly important for JIT systems:

1. Workers as assets
2. Cross-trained workers
3. Continuous improvement
4. Cost accounting
5. Leadership/project management

Workers as Assets A fundamental tenet of the JIT philosophy is that *workers are assets.* Well-trained and motivated workers are the heart of a JIT system. They are given more authority to make decisions than their counterparts in more traditional systems, but they are also expected to do more.

"People" Firms Boost Profits, Study Shows — NEWSCLIP

Companies that treat employees as valuable assets, invest in training programs and use innovative workplace practices are more profitable than those that don't, a study found.

The two-year look at the workplace strategies of American companies was conducted by the management consulting firm Ernst & Young LLP for the Labor Department.

"This is a path-breaking study that shows the surest way to profits and productivity is to treat employees as assets to be developed rather than costs to be cut," Labor Secretary Robert Reich said at a press conference.

For the study, researchers at Harvard and Wharton business schools in partnership with the Ernst & Young Center for Business Innovation, reviewed over 100 papers examining business practices of thousands of U.S. companies.

The report focused on the economic benefits to companies of such Japanese-inspired concepts of labor-management co-operation as Just-In-Time inventory, which moves components to factories only as they are needed.

Among the findings:

- Economic benefits to companies were greatest when they successfully integrated innovations in management and technology with the appropriate employee training and "empowerment" programs.
- Companies investing in employee development enjoy significantly higher market values on average than their industry peers.
- Companies that were first among their competitors in implementing new management practices reaped the largest rewards.

According to the study, Motorola, Inc. estimates it earns $30 for every $1 invested in employee training, while Xerox Corp. found that in cooperation with its employee union it has reduced manufacturing costs by 30 percent and halved the time needed to develop new products.

Cross-Trained Workers Workers are *cross-trained* to perform several parts of a process and operate a variety of machines. This adds to system flexibility because workers are able to help one another when bottlenecks occur or when a co-worker is absent. It also helps line balancing.

Continuous Improvement Workers in a JIT system have greater responsibility for quality than workers in traditional systems, and they are expected to be involved in problem solving and *continuous improvement.* JIT workers receive extensive training in statistical process control, quality improvement, and problem solving.

Problem solving is a cornerstone of any JIT system. Of interest are problems that interrupt, or have the potential to interrupt, the smooth flow of work through the system. When such problems surface, it becomes important to resolve them quickly. This may entail increasing inventory levels *temporarily* while the problem is investigated, but the intent of problem solving is to eliminate the problem, or at least greatly reduce the chances of it recurring.

andon System of lights used at each workstation to signal problems or slowdowns.

Problems that occur during production must be dealt with quickly. Some companies use a light system to signal problems; in Japan, such a system is called **andon.** Each workstation is equipped with a set of three lights. A green light means no problems, an amber light means a worker is falling a little bit behind, and a red light indicates a serious problem. The purpose of the light system is to keep others in the system informed and to enable workers and supervisors to immediately see when and where problems are occurring.

Japanese companies have been very successful in forming teams composed of workers and managers who routinely work on problems. Moreover, workers are encouraged to report problems and potential problems to the teams.

It is important that all levels of management actively support and become involved in problem solving. This includes a willingness to provide financial support and to recognize achievements. It is desirable to formulate goals with the help of workers, publicize the goals, and carefully document accomplishments. Goals give workers something tangible to strive for; recognition can help maintain worker interest and morale.

A central theme of a true just-in-time approach is to work toward continual improvement of the system—reducing inventories, reducing setup cost and time, improving quality, increasing the output rate, and generally cutting waste and inefficiency. Toward that end, problem solving becomes a way of life—a "culture" that must be assimilated into the thinking of management and workers alike. It becomes a never-ending quest for improving operations as all members of the organization strive to improve the system.

Workers in JIT systems have more stress than their counterparts in more traditional systems. Stress comes not only from their added authority and responsibility but also from the high-paced system they work in, where there is little slack and a continual push to improve.

Cost Accounting Another feature of some JIT systems is the method of allocating overhead. Traditional accounting methods sometimes distort overhead allocation because they allocate it on the basis of direct labor hours. However, that approach does not always accurately reflect the consumption of overhead by different jobs. In addition, the number of direct labor hours in some industries has declined significantly over the years and now frequently accounts for a relatively small portion of the total cost. Conversely, other costs now represent a major portion of the total cost. Therefore, labor-intensive jobs (i.e., those that use relatively large proportions of direct labor) may be assigned a disproportionate share of overhead, one that does not truly reflect actual costs. That in turn can cause managers to make poor decisions. Furthermore, the need to track direct labor hours can itself involve considerable effort.

activity-based costing Allocation of overhead to specific jobs based on their percentage of activities.

One alternative method of allocating overhead is **activity-based costing.** This method is designed to more closely reflect the actual amount of overhead consumed by a particular job or activity. Activity-based costing first identifies traceable costs and then assigns those costs to various types of activities such as machine setups, inspection, machine hours, direct labor hours, and movement of materials. Specific jobs are then assigned overhead based on the percentage of activities they consume.

Leadership/Project Management Another feature of JIT relates to *leadership.* Managers are expected to be leaders and facilitators, not order givers. JIT encourages two-way communication between workers and managers.

Manufacturing Planning and Control

Six elements of manufacturing planning and control are particularly important for JIT systems:

1. Level loading
2. Pull systems
3. Visual systems
4. Close vendor relationships
5. Reduced transaction processing
6. Preventive maintenance and housekeeping

Level Loading JIT systems place a strong emphasis on achieving stable, level daily mix schedules. Toward that end, the master production schedule is developed to provide *level capacity* *loading.* That may entail a rate-based production schedule instead of the more familiar quantity-based schedule. Moreover, once established, production schedules are relatively fixed over a short time horizon, and this provides certainty to the system. Even so, some adjustments may be needed in day-to-day schedules to achieve level capacity requirements. Suppliers like level loading because it means smooth demand for them.

A level production schedule requires smooth production. When a company produces different products or product models, it is desirable to produce in small lots (to minimize work-in-process inventory and to maintain flexibility) and to spread the production of the different products throughout the day to achieve smooth production. The extreme case would be to produce one unit of one product, then one of another, then one of another, and so on. While this approach would allow for maximum smoothness, it would generally not be practical because it would generate excessive setup costs.

Mixed-model sequencing begins with daily production requirements of each product or model. For instance, suppose a department produces three models, A, B, and C, with these daily requirements:

Model	Daily Quantity
A	10
B	15
C	5

There are three issues that need to be resolved. One is which sequence to use (C-B-A, A-C-B, etc.), another is how many times (i.e., cycles) the sequence should be repeated daily, and the third is how many units of each model to produce in each cycle.

The choice of sequence can depend on several factors, but the key one is usually the setup time or cost, which may vary depending on the sequence used. For instance, if two of the models, say A and C, are quite similar, the sequences A-C and C-A may involve only minimal setup changes, whereas the setup for model B may be more extensive. Choosing a sequence that has A-C or C-A will result in about 20 percent fewer setups over time than having B produced between A and C on every cycle.

The number of cycles per day depends on the daily production quantities. If every model is to be produced in every cycle, which is often the goal, determining the smallest integer that can be evenly divided into each model's daily quantity will indicate the number of cycles. This will be the fewest number of cycles that will contain one unit of the model with the lowest quantity requirements. For models A, B, and C shown in the preceding table, there should be five cycles (5 can be evenly divided into each quantity). High setup costs may cause a manager to use fewer cycles, trading off savings in setup costs and level production. If dividing by the smallest daily quantity does not yield an integer value for each model, a manager may opt for using the smallest production quantity to select a number of cycles, but then produce more of some items in some cycles to make up the difference.

Sometimes a manager determines the number of units of each model in each cycle by dividing each model's daily production quantity by the number of cycles. Using five cycles per day would yield the following:

Model	Daily Quantity	Units per Cycle
A	10	10/5 = 2
B	15	15/5 = 3
C	5	5/5 = 1

These quantities may be unworkable due to restrictions on lot sizes. For example, Model B may be packed four to a carton, so producing three units per cycle would mean that at times finished units (inventory) would have to wait until sufficient quantities were available to fill a crate. Similarly, there may be standard production lot sizes for some operations. A heat-treating process might involve a furnace that can handle six units at a time. If the different models require different furnace temperatures, they could not be grouped. What would be necessary here is an analysis of the trade-off between furnace lot size and the advantages of level production.

EXAMPLE 1

Determine a production plan for these three models using the sequence A-B-C:

Model	Daily Quantity
A	7
B	16
C	5

SOLUTION

The smallest daily quantity is 5, but dividing the other two quantities by 5 does not yield integers. The manager might still decide to use five cycles. Producing one unit of Models A and C and three units of Model B in each of the five cycles would leave the manager short two units of Model A and one unit of Model B. The manager might decide to intersperse those units like this to achieve nearly level production:

Cycle	1	2	3	4	5
Pattern	A B(3) C	A(2) B(3) C	A B(4) C	A(2) B(3) C	A B(3) C
Extra unit(s)		A	B	A	

If the requirement for Model A had been 8 units a day instead of 7, the manager might decide to use the following pattern:

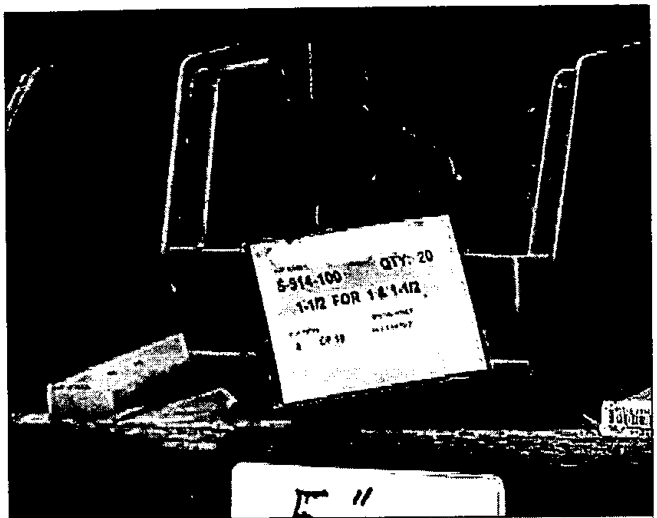
Cycle	1	2	3	4	5
Pattern	A(2) B(3) C	A B(3) C	A(2) B(4) C	A B(3) C	A(2) B(3) C
Extra unit(s)	A		A B		A

push system Work is pushed to the next station as it is completed.

pull system A workstation pulls output from the preceding station as it is needed.

Pull Systems The terms *push* and *pull* are used to describe two different systems for moving work through a production process. In traditional production environments, a **push system** is used: When work is finished at a workstation, the output is *pushed* to the next station; or, in the case of the final operation, it is pushed on to final inventory. Conversely, in a **pull system,** control of moving the work rests with the following operation; each workstation *pulls* the output from the preceding station as it is needed; output of the final operation is pulled by customer demand or the master schedule. Thus, in a pull system, work moves on in response to demand from the next stage in the process, whereas in a push system, work moves on as it is completed, without regard to the next station's readiness for the work. Consequently, work may pile up at workstations that fall behind schedule because of equipment failure or the detection of a problem with quality.

JIT system communication moves backward through the system from station to station. Each workstation (i.e., customer) communicates its need for more work to the preceding workstation (i.e., supplier), thereby assuring that supply equals demand. Work moves "just in time" for the next operation; the flow of work is thereby coordinated, and the accumulation of excessive inventories between operations is avoided. Of course, some inventory is usually present because operations are not instantaneous. If a workstation waited until it received a request from the next workstation before starting its work, the next station would have to wait for the preceding station to perform its work. Therefore, by design, each workstation produces just enough output to meet the (anticipated) demand of the next station. This can be accomplished by having the succeeding workstation communicate its need for input sufficiently ahead of time to allow the preceding station to do the work. Or there can be a small buffer of stock between stations; when the buffer decreases to a certain level, this signals the preceding station to produce enough output to replenish the buffer supply. The size of the buffer supply depends on the cycle time at the preceding workstation. If the cycle time is short, the station will need little or no buffer; if the cycle time is long, it will need a considerable amount of buffer. However, production occurs only in response to *usage* of the succeeding station; work is still pulled by the demand generated by the next operation.



At TriState Industries, a kanban system is in effect to move work through the production system. Shown here, a kanban card provides the authorization to move or work on parts.

Special carts were designed that, when filled, act as a visual signal that they are ready to be moved to the next work cell. An empty cart indicates that it is time to produce, in order to refill the cart.

Visual Systems In a pull system work flow is dictated by "next-step demand." A system can communicate such demand in a variety of ways, including a shout or a wave, but by far the most commonly used device is the **kanban** card. *Kanban* is a Japanese word meaning "signal" or "visible record." When a worker needs materials or work from the preceding station, he or she uses a kanban card. In effect, the kanban card is the *authorization* to move or work on parts. In kanban systems, no part or lot can be moved or worked on without one of these cards.

kanban Card or other device that communicates demand for work or materials from the preceding station.

The system works this way: A kanban card is affixed to each container. When a workstation needs to replenish its supply of parts, a worker goes to the area where these parts are stored and withdraws one container of parts. Each container holds a predetermined quantity. The worker removes the kanban card from the container and posts it in a designated spot where it will be clearly visible, and the worker moves the container to the workstation. The posted kanban is then picked up by a stock person who replenishes the stock with another container, and so on down the line. Demand for parts triggers a replenishment, and parts are supplied as usage dictates. Similar withdrawals and replenishments—all controlled by kanbans—occur all the way up and down the line from vendors to finished-goods inventories. If supervisors decide the system is too loose because inventories are building up, they may decide to tighten the system and withdraw some kanbans. Conversely, if the system seems too tight, they may introduce additional kanbans to bring the system into balance. Vendors also can influence the number of containers. Moreover, trip times can affect the number: Longer trip times may lead to fewer but larger containers, while shorter trip times may involve a greater number of small containers.

It is apparent that the number of kanban cards in use is an important variable. One can compute the ideal number of kanban cards using this formula:

$$N = \frac{DT(1+X)}{C} \qquad (14\text{–}1)$$

where

N = Total number of containers (1 card per container)

D = Planned usage rate of using work center

T = Average waiting time for replenishment of parts plus average production time for a container of parts

X = Policy variable set by management that reflects possible inefficiency in the system (the closer to 0, the more efficient the system)

C = Capacity of a standard container (should be no more than 10 percent of daily usage of the part)

Note that D and T must use the same units (e.g., minutes, days).

EXAMPLE 2

Usage at a work center is 300 parts per day, and a standard container holds 25 parts. It takes an average of .12 day for a container to complete a circuit from the time a kanban card is received until the container is returned empty. Compute the number of kanban cards (containers) needed if $X = .20$.

SOLUTION

$N = ?$

$D = 300$ parts per day

$T = .12$ day

$C = 25$ parts per container

$X = .20$

$$N = \frac{300(.12)(1 + .20)}{25} = 1.728 \text{ (round to two containers)}$$

Note: Rounding up will cause the system to be looser, and rounding down will cause it to be tighter. Usually, rounding up is used.

Although the goals of MRP and kanban are essentially the same (i.e., to improve customer service, reduce inventories, and increase productivity), their approaches are different. Neither MRP nor kanban is a stand-alone system—each exists within a larger framework. MRP is a computerized system; kanban is a manual system.

Kanban systems usually have very small lot sizes, short lead times, and high-quality output, and they exemplify teamwork. Kanban is essentially a two-bin type of inventory: Supplies are replenished semiautomatically when they reach a predetermined level. MRP is more concerned with projecting requirements and with planning and scheduling operations.

A major benefit of the kanban system is its simplicity; a major benefit of MRP is its ability to handle complex planning and scheduling. In addition, MRP II enables management to answer "what if" questions for capacity planning.

The philosophies that underlie JIT systems are quite different from those traditionally held by manufacturers. Nonetheless, both approaches have their merits, so it probably would not make sense in most instances to switch from one method of operation to the other. Moreover, to do so would require a tremendous effort. It is noteworthy that at the same time that Western manufacturers are studying kanban systems, some Japanese manufacturers are studying MRP systems. This suggests the possibility that either system could be improved by incorporating selected elements of the other. That would take careful analysis to determine which elements to incorporate as well as carefully implementing selected elements, and close monitoring to assure that intended results were achieved.

Whether manufacturers should adopt the kanban method is debatable. Some form of it may be useful, but kanban is merely an information system; by itself it offers little in terms of helping manufacturers become more competitive or productive. By the same token, MRP alone will not achieve those results either. Instead, it is the overall approach to manufacturing that is crucial; it is the commitment and support of top management and the continuing efforts of all levels of management to find new ways to improve their manufacturing planning and control techniques, and to adapt those techniques to fit their particular circumstances, that will determine the degree of success.

Comment The use of either JIT or MRP does not preclude the use of the other. In fact, it is not unusual to find the two systems used in the same production facility. Some Japanese manufacturers, for example, are turning to MRP systems to help them plan production. Both approaches have their advantages and limitations. MRP systems provide the capability to explode the bill of materials to project timing and material requirements that can then be used to plan production. But the MRP assumption of fixed lead times and infinite capacity can often result in significant problems. At the shop floor level, the discipline of a JIT system, with materials pull, can be very effective. But JIT works best when there is a uniform flow through the shop; a variable flow requires buffers and this reduces the advantage of a pull system.

In effect, some situations are more conducive to a JIT approach, others to an MRP approach. Still others can benefit from a hybrid of the two.

Developing the JIT Philosophy

READING

Successful implementation of JIT requires involvement from all levels of management in all disciplines

"Our improvement in just-in-time has to be credited to the involvement of higher management and management across many disciplines," says Tom Jensch, Avon's director of materials management.

Every two weeks, at Avon's headquarters in New York City, senior management holds an inventory meeting to discuss progress in JIT. Included in that meeting are top-level managers from finance, marketing, merchandising, purchasing and strategic planning.

"It's a working meeting," says Jensch. "You don't just go in and listen to how the inventory numbers came in at the end of the month. We talk about specific marketing plans for items. How risky are they from an inventory standpoint? What can we do to minimize the risk? We can end up affecting designs of new products by getting away from unique containers and using stock containers if that's important to reduce the inventory risks. We talk about marketing flow and what we are going to do if a product oversells or undersells."

Management involvement doesn't begin and end with that one meeting. "We hold a monthly meeting with lower levels of management and nonmanagement people where we process ideas that have come out of the senior management meeting," says Jensch. "We are working to come up with new ideas. In this meeting are the appropriate people from marketing, finance, purchasing and materials control who are actually the hands-on inventory people. They are much closer to the front lines. It's a communication meeting, to share information and then follow up on various inventory projects we have initiated."

In addition, management from New York meets with inventory control people from Avon's three manufacturing facilities every six weeks. "The purpose of these meetings is to review inventory progress with the manufacturing facilities, to bring to them some of the new ideas that have been stimulated here in New York, to hear from them the new ideas and opportunities that they've identified and to see how we can work together to best process those ideas," says Jensch.

One of the ideas that went through this process and was implemented was the Vendor Proximity Program—the development of suppliers closer to Avon's manufacturing facilities. "Personnel at Avon's manufacturing plant in Suffern, N.Y., were having great success with JIT and we realized that all of the plant's suppliers were within a one-day transit time," says Jensch. After discussing this at inventory meetings, the company decided to seek vendors closer to its other two manufacturing sites in Morton Grove, Ill., and Springdale, Ohio.

Source: Reprinted with permission of *Purchasing*, September 1990.

Close Vendor Relationships JIT systems typically have *close relationships with vendors,* who are expected to provide frequent small deliveries of high-quality goods. Traditionally, buyers have assumed the role of monitoring the quality of purchased goods, inspecting shipments for quality and quantity, and returning poor-quality goods to the vendor for rework. JIT systems have little slack, so poor-quality goods cause a disruption in the smooth flow of work. Moreover, the inspection of incoming goods is viewed as inefficient because it does not add value to the product. For these reasons, the burden of ensuring quality shifts to the vendor. Buyers work with vendors to help them achieve the desired quality levels and to impress upon them the importance of consistent, high-quality goods. The ultimate goal of the buyer is to be able to *certify* a vendor as a producer of high-quality goods. The implication of certification is that a vendor can be relied on to deliver high-quality goods without the need for buyer inspection.

Suppliers also must be willing and able to ship in small lots on a regular basis. Ideally, suppliers themselves will be operating under JIT systems. Buyers can often help suppliers convert to JIT production based on their own experiences. In effect, the supplier becomes part of an extended JIT system that integrates the facilities of buyer and supplier. Integration is easier when a supplier is dedicated to only one or a few buyers. In practice, a supplier is likely to have many different buyers, some using traditional systems and others using JIT. Consequently, compromises may have to be made by both buyers and suppliers.

Traditionally, a spirit of cooperation between buyer and seller has not been present; buyers and vendors have had a somewhat adversarial relationship. Buyers have generally regarded price as a major determinant in sourcing, and they have typically used *multiple-source* purchasing, which means having a list of potential vendors and buying from several to avoid getting locked into a sole source. In this way, buyers play vendors off against each other to get better pricing arrangements or other concessions. The downside is that vendors cannot rely on a long-term relationship with a buyer, and they feel no loyalty to a particular buyer. Furthermore, vendors have often sought to protect themselves from losing a buyer by increasing the number of buyers they supply.

Under JIT purchasing, good vendor relationships are very important. Buyers take measures to reduce their lists of suppliers, concentrating on maintaining close working relationships with a few good ones. Because of the need for frequent, small deliveries, many buyers attempt to find local vendors to shorten the lead time for deliveries and to reduce lead time variability. An added advantage of having vendors nearby is quick response when problems arise.

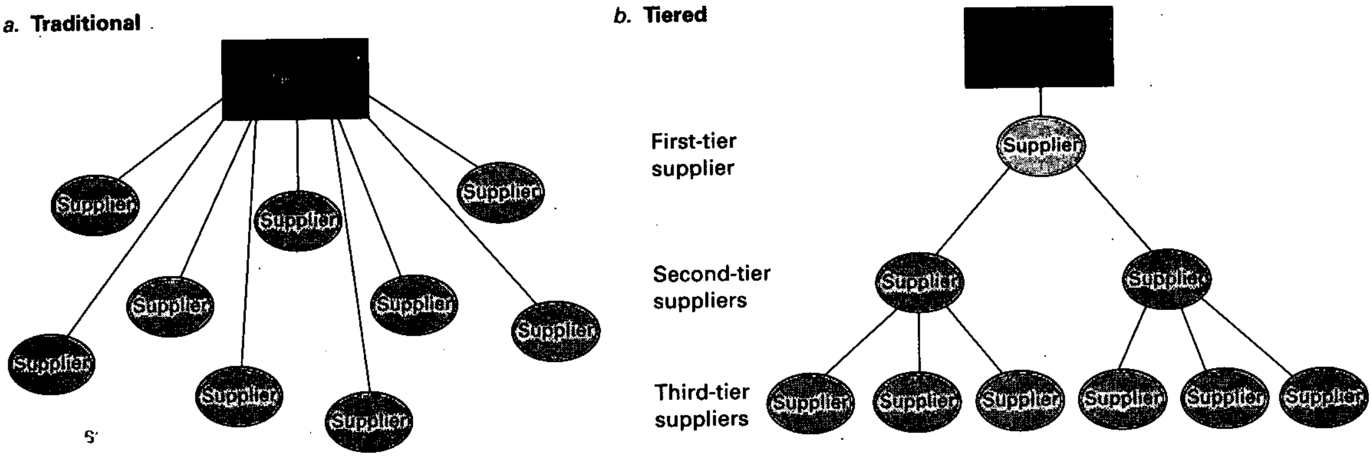
JIT purchasing is enhanced by long-term relationships between buyers and vendors. Vendors are more willing to commit resources to the job of shipping according to a buyer's JIT system given a long-term relationship. Moreover, price often becomes secondary to other aspects of the relationship (e.g., consistent high quality, flexibility, frequent small deliveries, and quick response to problems).

Supplier Tiers A key feature of many lean production systems is the relatively small number of suppliers used. In traditional production, companies often deal with hundreds or even thousands of suppliers in a highly centralized arrangement not unlike a giant wheel with many spokes. The company is at the hub of the wheel, and the spokes radiate out to suppliers, each of whom must deal directly with the company. In traditional systems, a supplier does not know the other suppliers or what they are doing. Each supplier works to specifications provided by the buyer. Suppliers have very little basis (or motivation) for suggesting improvements. Moreover, as companies play one supplier off against others, the sharing of information is more risky than rewarding. In contrast, lean production companies may employ a tiered approach for suppliers: They use relatively few first-tier suppliers who work directly with the company or who supply major subassemblies. The first-tier suppliers are responsible for dealing with second-tier suppliers who provide components for the subassemblies, thereby relieving the final buyer from dealing with large numbers of suppliers.

The automotive industry provides a good example of this situation. Suppose a certain car model has an electric seat. The seat and motor together might entail 250 separate parts. A traditional producer might use more than 30 suppliers for the electric seat, but a lean producer might use a single (first-tier) supplier who has the responsibility for the entire seat unit. The company would provide specifications for the overall unit, but leave to the supplier the details of the motor, springs, and so on. The first-tier supplier, in turn, might subcontract the motor to a second-tier supplier, the track to another second-tier supplier, and the cushions and fabric to still another. The second-tier suppliers might subcontract some of their work to third-tier suppliers, and so on. Each tier has only to deal with those just above it or just below it. Suppliers on each level are encouraged to work with each other, and they are motivated to do so because that increases the probability that the resulting item (the seat) will meet or exceed the final buyer's expectations. In this "team of suppliers" approach, all suppliers benefit from a successful product, and each supplier bears full responsibility for the quality of its portion of the product. Figure 14.4 illustrates the difference between the traditional approach and the tiered approach.

FIGURE 14.4

Traditional supplier network compared to supplier tiers



Reduced Transaction Processing Traditional manufacturing systems often have many built-in transactions that do not add value. In their well-known article, "The Hidden Factory,"[2] Jeffrey G. Miller and Thomas Vollmann identify a laundry list of transaction processing that comprises a "hidden factory" in traditional manufacturing planning and control systems, and point out the tremendous cost burden that results. The transactions can be classified as logistical, balancing, quality, or change transactions.

Logistical transactions include ordering, execution, and confirmation of materials transported from one location to another. Related costs cover shipping and receiving personnel, expediting orders, data entry, and data processing.

Balancing transactions include forecasting, production planning, production control, procurement, scheduling, and order processing. Associated costs relate to the personnel involved in these and supporting activities.

Quality transactions include determining and communicating specifications, monitoring, recording, and followup activities. Costs relate to appraisal, prevention, internal failures (e.g., scrap, rework, retesting, delays, administration activities) and external failures (e.g., warranty costs, product liability, returns, potential loss of future business).

Change transactions primarily involve engineering changes and the ensuing changes generated in specifications, bills of material, scheduling, processing instructions, and so on. Engineering changes are among the most costly of all transactions.

JIT systems cut transaction costs by reducing the number and frequency of transactions. For example, suppliers deliver goods directly to the production floor, bypassing the storeroom entirely, thereby avoiding the transactions related to receiving the shipment into inventory storage and later moving the materials to the production floor. In addition, vendors are certified for quality, eliminating the need to inspect incoming shipments for quality. The unending quest for quality improvement that pervades JIT systems eliminates many of the above-mentioned quality transactions and their related costs. The use of bar coding (not exclusive to JIT systems) can reduce data entry transactions and increase data accuracy.

Preventive Maintenance and Housekeeping Because JIT systems have very little in-process inventory, equipment breakdowns can be extremely disruptive. To minimize breakdowns, companies use **preventive maintenance** programs, which emphasize maintaining equipment in good operating condition and replacing parts that have a tendency to fail before they fail. Workers are often responsible for maintaining their own equipment.

preventive maintenance Maintaining equipment in good operating condition and replacing parts that have a tendency to fail before they actually do fail.

[2] Jeffrey G. Miller and Thomas Vollmann, "The Hidden Factory," *Harvard Business Review*, September–October 1985, pp. 141–50.

Even with preventive maintenance, occasional equipment failures will occur. Companies must be prepared for this, so they can quickly return equipment to working order. This may mean maintaining supplies of critical spare parts and making other provisions for emergency situations, perhaps maintaining a small force of repair people or training workers to do certain repairs themselves. Note that when breakdowns do occur, they indicate potential opportunities to be exploited in a JIT environment.

housekeeping Maintaining a workplace that is clean and free of unnecessary materials.

Housekeeping involves keeping the workplace clean as well as keeping it free of any materials that are not needed for production, because those materials take up space and may cause disruptions to the work flow.

JIT systems have been described and compared with traditional manufacturing systems in the preceding pages. Table 14.3 provides a brief overview of those comparisons.

TABLE 14.3
Comparison of JIT/lean and traditional production philosophies

Factor	Traditional	JIT
Inventory	Much, to offset forecast errors, late deliveries	Minimal necessary to operate
Deliveries	Few, large	Many, small
Lot sizes	Large	Small
Setups, runs	Few, long runs	Many, short runs
Vendors	Long-term relationships are unusual	Partners
Workers	Necessary to do the work	Assets

TRANSITIONING TO A JIT SYSTEM

The success of JIT systems in Japan and the United States has attracted keen interest among other traditional manufacturers.

Planning a Successful Conversion

To increase the probability of successful transition, companies should adopt a carefully planned approach that includes the following elements:

1. Make sure top management is committed to the conversion and that they know what will be required. Make sure that management is involved in the process and knows what it will cost, how long it will take to complete the conversion, and what results can be expected.
2. Study the operations carefully; decide which parts will need the most effort to convert.
3. Obtain the support and cooperation of workers. Prepare training programs that include sessions in setups, maintenance of equipment, cross-training for multiple tasks, cooperation, and problem solving. Make sure workers are fully informed about what JIT is and why it is desirable. Reassure workers that their jobs are secure.
4. Begin by trying to reduce setup times while maintaining the current system. Enlist the aid of workers in identifying and eliminating existing problems (e.g., bottlenecks, poor quality).
5. Gradually convert operations, beginning at the *end* of the process and working *backward*. At each stage, make sure the conversion has been relatively successful before moving on. Do not begin to reduce inventories until major problems have been resolved.
6. As one of the last steps, convert suppliers to JIT and be prepared to work closely with them. Start by narrowing the list of vendors, identifying those who are willing to embrace the JIT philosophy. Give preference to vendors who have long-term track records of reliability. Use vendors located nearby if quick response time is important. Establish long-term commitments with vendors. Insist on high standards of quality and adherence to strict delivery schedules.
7. Be prepared to encounter obstacles to conversion.

Obstacles to Conversion

Converting from a traditional system to a JIT system may not be smooth. For example, *cultures* vary from organization to organization. Some cultures relate better to the JIT philosophy than others. If a culture doesn't relate, it can be difficult for an organization to change its culture within a short time. Also, manufacturers that operate with large amounts of inventory to handle varying customer demand may have difficulty acclimating themselves to less inventory.

Some other obstacles include the following:

1. Management may not be totally committed or may be unwilling to devote the necessary resources to conversion. This is perhaps the most serious impediment because the conversion is probably doomed without serious commitment.
2. Workers and/or management may not display a cooperative spirit. The system is predicated on cooperation. Managers may resist because JIT shifts some of the responsibility from management to workers and gives workers more control over the work. Workers may resist because of the increased responsibility and stress.
3. Suppliers may resist for several reasons:
   a. Buyers may not be willing to commit the resources necessary to help them adapt to the JIT systems.
   b. They may be uneasy about long-term commitments to a buyer.
   c. Frequent, small deliveries may be difficult, especially if the supplier has other buyers who use traditional systems.
   d. The burden of quality control will shift to the supplier.
   e. Frequent engineering changes may result from continuing JIT improvements by the buyer.

Comment JIT systems require a cooperative spirit among workers, management, and vendors. Unless that is present, it is doubtful that a truly effective JIT system can be achieved. The Japanese have been very successful in this regard, partly because respect and cooperation are ingrained in the Japanese culture. In Western cultures, workers, managers, and vendors have historically been strongly at odds with each other. Consequently, a major consideration in converting to a JIT system is whether a spirit of mutual respect and cooperation can be achieved. This requires an appreciation of the importance of cooperation and a tenacious effort by management to instill and maintain that spirit.

The Downside of Conversion to a JIT System Despite the many advantages of JIT production systems, an organization must take into account a number of other considerations when planning a conversion.

The key considerations are the time and cost requirements for successful conversion, which can be substantial. But it is absolutely essential to eliminate the major sources of disruption in the system. Management must be prepared to commit the resources necessary to achieve a high level of quality and to function on a tight schedule. That means attention to even the smallest of details during the design phase and substantial efforts to debug the system to the point where it runs smoothly. Beyond that, management must be capable of responding quickly when problems arise, and both management and workers must be committed to the continuous improvement of the system. Although each case is different, a general estimate of the time required for conversion is one to three years.

Another consideration pertains to small lot sizes. While small lot sizes allow flexibility in changing the product mix and reduced carrying costs and space requirements, they typically result in (1) increased transportation costs and (2) traffic congestion due to frequent deliveries.

JIT IN SERVICES

The discussion of just-in-time has focused on manufacturing simply because that is where it was developed, and where it has been used most often. Nonetheless, services can and do www.dominos.com

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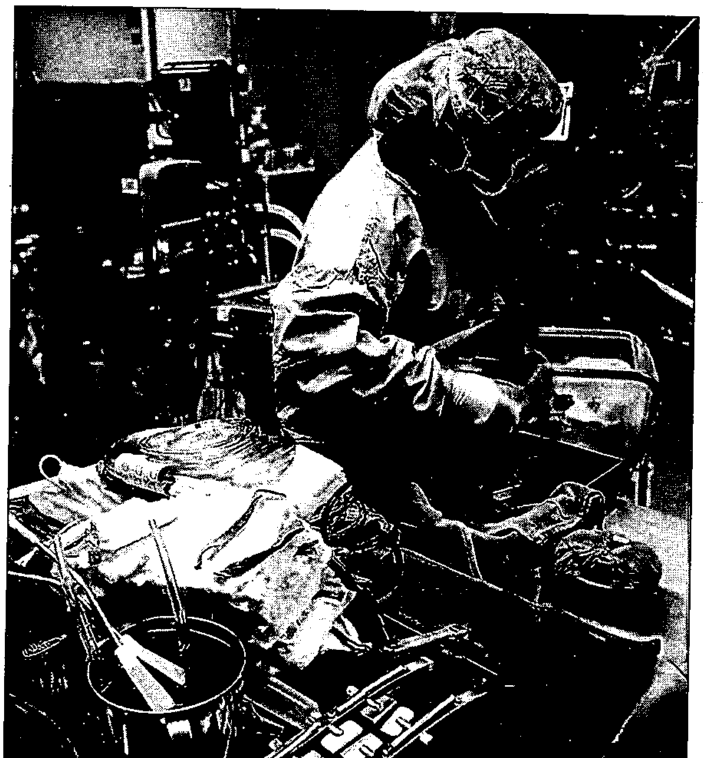
benefit from many JIT concepts. When just-in-time is used in the context of services, the focus is often on the time needed to perform a service—because speed is often an important order winner for services. Some services do have inventories of some sort, so inventory reduction is another aspect of JIT that can apply to services. Examples of speedy delivery ("available when requested") are Domino's Pizza, Federal Express and Express Mail, fast-food restaurants, and emergency services. Other examples include just-in-time publishing and work cells at fast-food restaurants.

In addition to speed, JIT services emphasize consistent, high-quality, standard work methods, flexible workers; and close supplier relationships.

Process improvement and problem solving can contribute to streamlining a system, resulting in increased customer satisfaction and higher productivity. Some of the ways JIT benefits can be achieved in services are·

- Eliminate disruptions. For example, try to avoid having workers who are servicing customers also answer telephones.
- Make the system flexible. This can cause problems unless approached carefully. Often, it is desirable to standardize work because that can yield high productivity. On the other hand, being able to deal with variety in task requirements can be a competitive advantage. One approach might be to train workers so that they can handle more variety. Another might be to assign work according to specialties, with certain workers handling different types of work according to their specialty.
- Reduce setup times and processing times. Have frequently used tools and spare parts readily available. Additionally, for service calls, try to estimate what parts and supplies might be needed so they will be on hand, and avoid carrying huge inventories.
- Eliminate waste. This includes errors and duplicate work. Keep the emphasis on quality and uniform service.
- Minimize work-in-process. Examples include orders waiting to be processed, calls waiting to be answered, packages waiting to be delivered, trucks waiting to be unloaded or loaded, applications waiting to be processed.
- Simplify the process, especially when customers are part of the system (self-service systems including retail operations, ATM and vending machines, service stations, etc.).



At Duke University Medical Center, the supplies for a bypass operation arrive from Baxter International packaged in the order in which they will be used during the surgery. Baxter provides this computer-based service along with the supplies, giving it a competitive advantage in the hospital supply industry.

JIT service can be a major competitive advantage for companies that can achieve it. An important key to JIT service is the ability to provide service when it is needed. That requires flexibility on the part of the provider, which generally means short setup times, and it requires clear communication on the part of the requester. If a requester can determine when it will need a particular service, a JIT server can schedule deliveries to correspond to those needs, eliminating the need for continual requests, and reducing the need for provider flexibility—and therefore probably reducing the cost of the JIT service.

JIT II

In some instances, companies allow *suppliers* to manage restocking of inventory obtained from the suppliers. A supplier representative works right in the company's plant, making sure there is an appropriate supply on hand. The term *JIT II* is used to refer to this practice.

JIT II

READING

Faced with a mandate to freeze hiring, but needing help, Lance Dixon, then director of purchasing and logistics for Bose Corp. (Framingham, MA), came up with an innovative idea that not only solved the problem, but added numerous other benefits. The solution: Arrange for supplier representatives to work on-site at Bose on a full-time or almost full-time basis.

The concept became known as JIT II—the second iteration of JIT supply management. The supplier reps, called "in-plants," place orders to their own companies, relieving the customer's buyers from this task. Many also become involved at a deeper level, such as participating in new product development projects, manufacturing planning (concurrent planning), and so on.

"One of the real 'bangs for the buck' of JIT II is that suppliers, who have more expertise on the parts they supply than their customers do, can suggest modifications during the design phase that customers would not know about on their own," explains Bill Grimes, former vice president of global supply for Honeywell and now an independent consultant based in Plymouth, MN.

The concept came along at the right time. In the early 1990s, more and more companies were beginning to understand the value of developing closer relationships with key suppliers.

JIT II has exploded in popularity. Customers embraced the benefit of having "free" resident experts available on a full-time basis, rather than having to place calls to suppliers for answers or solutions, or having to wait for supplier reps to show up for their appointed visits. Suppliers embraced the concept just as well—relishing the opportunity to become ensconced in their customer facilities, effectively doing an "end run" around their competitors.

Dixon, who is still with Bose, but who is also the executive director of the JIT II Education & Research Center, offers a partial list of well-known companies that currently use JIT II: Beckman Coulter, Foxboro Company, Gulfstream Aerospace, Harley-Davidson, Honeywell, IBM, Johnson Wax, Lotus, Maytag, Motorola, Siemens, Sun Microsystems, Varian, and Westinghouse. "Most companies have five to ten inplants, but some have dozens," reports Dixon.

"JIT II does several things to improve the bottom line," reports Grimes. "It replaces the traditional purchasing organization with a more strategically-focused organization, requires less use of customers' resources, and provides customers with on-site expertise."

The constant need for new and innovative products is also a good sign for the continued health of JIT II. "Having inplants place orders is OK, but the real value comes from new sales," explains Dixon. "As the demand for new technology and new products increases, companies realize the value of having inplants available to introduce new ideas. Suppliers are there to show you how their new products and services can assist you with your new products."

The trend toward outsourcing also dovetails well with JIT II. "In specific, JIT II encourages suppliers who are in outsourcing arrangements with their customers to move their facilities as close to their customers as possible," states Dixon. "Some suppliers build plants right next to customer facilities." In a Ford Motor plant in Spain, for example, suppliers are in a ring around the Ford production plant and send parts via conveyors over the streets. In other instances, suppliers install capital equipment inside customer facilities, and supplier employees perform pre-press or production work onsite.

Ah, but what about technology? Doesn't the Internet, where transactions and interactions can take place at lightning speed, reduce the need for face-to-face relationships? In some instances, this may be true. In the area of new product development, for example, there is new technology called electronic collaborative design, where companies and their suppliers can work on designs interactively and simultaneously via the Internet from different locations around the world. As this technology expands, will the need for inplants decrease? "We see a

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number of companies using this new technology as an addition to JIT II, but not in place of it," replies Grimes. "Granted, people may need to meet face to face less often, but the need to work closely still exists." In some cases, according to Grimes, in-plants will interact electronically with colleagues at their employers' locations via the Internet on new product design, but do so from customers' locations.

Regardless of how prevalent communication technology becomes, though, companies tend to continue to understand the value of personal relationships. "E-procurement will find its place in purchasing transactions in the long run, but I don't believe it will replace the relationship management strategies that customers have with their suppliers," continues Grimes. "For example, when commodities are in short supply, or when there are large price fluctuations, the depth of the relationship customers have with their suppliers will determine who will get parts and who won't."

Source: Excerpted from William Atkinson, "Does JIT II Still Work in the Internet Age?" *Purchasing*, September 6, 2001.

Operations Strategy

The JIT/lean operation offers new perspectives on operations that must be given serious consideration by managers in repetitive systems who wish to be competitive.

Potential adopters should carefully study the requirements and benefits of lean production systems, as well as the difficulties and strengths of their current systems, before making a decision on whether to convert. Careful estimates of time and cost to convert, and an assessment of how likely workers, managers, and suppliers are to cooperate in such an approach, are essential.

The decision to convert can be sequential, giving management an opportunity to gain first-hand experience with portions of JIT/lean operations without wholly committing themselves. For instance, improving vendor relations, reducing setup times, improving quality, and reducing waste and inefficiency are desirable goals in themselves. Moreover, a level production schedule is a necessary element of a JIT system, and achieving that will also be useful under a traditional system of operation.

Supplier management is critical to a JIT operation. Generally, suppliers are located nearby to facilitate delivery on a daily or even hourly basis. Moreover, suppliers at every stage must gauge the ability of their production facilities to meet demand requirements that are subject to change.

SUMMARY

Just-in-time (JIT) is a system of lean production used mainly in repetitive operations, in which goods move through the system and tasks are completed just in time to maintain the schedule. JIT systems require very little inventory because successive operations are closely coordinated.

The ultimate goal of a JIT system is to achieve a balanced, smooth flow of production. Supporting goals include eliminating disruptions to the system, making the system flexible, and eliminating waste. The building blocks of a JIT system are product design, process design, personnel and organization, and manufacturing planning and control.

Lean systems require the elimination of sources of potential disruption to the even flow of work. High quality is essential because problems with quality can disrupt the process. Quick, low-cost setups, special layouts, allowing work to be pulled through the system rather than pushed through, and a spirit of cooperation are important features of lean systems. So, too, are problem solving aimed at reducing disruptions and making the system more efficient, and an attitude of working toward continual improvement.

Key benefits of JIT/lean systems are reduced inventory levels, high quality, flexibility, reduced lead times, increased productivity and equipment utilization, reduced amounts of scrap and rework, and reduced space requirements. The risks stem from the absence of buffers, such as extra personnel and inventory stockpiles to fall back on if something goes wrong. The possible results of risks include lost sales and lost customers.

Careful planning and much effort are needed to achieve a smoothly functioning system in which all resources needed for production come together at precisely the right time throughout the process. Raw materials and purchased parts must arrive when needed, fabricated parts and subassemblies must be ready when needed for final assembly, and finished goods must be delivered to customers when needed. Special attention must be given to reducing the risk of disruptions to the system as well as rapid response to resolving any disruptions that do occur. Usually, a firm must redesign its facilities and rework labor

contracts to implement JIT. Teamwork and cooperation are important at all levels, as are problem-solving abilities of workers and an attitude of continuous improvement.

Table 14.4 provides an overview of JIT.

TABLE 14.4
Overview of JIT

JIT originally referred to the timing of movement of materials in a production system to meet customer demand, whether the "customer" was the final consumer or another operation in the production process. It became known for having minimal inventories. It has now come to mean operating a balanced system with minimum waste. In the JIT philosophy, there are six types of waste:

- Waste from overproduction.
- Waste of waiting time.
- Transportation waste.
- Processing waste.
- Inventory waste.
- Waste of motion.

Elements of JIT include:

- Smooth flow of work (the ultimate goal).
- Elimination of waste.
- Continuous improvement.
- Eliminating anything that does not add value.
- Simple systems that are easy to manage.
- Use of product layouts that minimize time spent moving materials and parts.
- Quality at the source: each worker is responsible for the quality of his or her output.
- **Poka-yoke:** fail-safe tools and methods to prevent mistakes.
- Preventive maintenance to reduce the risk of equipment breakdown.
- Good housekeeping: an orderly and clean workplace.
- Setup time reduction.
- Cross-trained workers.
- A pull system.

poka-yoke Fail-safe tools and methods to prevent mistakes.

KEY TERMS

SOLVED PROBLEMS

Problem 1

Determine the number of containers needed for a workstation that uses 100 parts per hour if the time for a container to complete a cycle (move, wait, empty, return, fill) is 90 minutes and a standard container holds 84 parts. An inefficiency factor of .10 is currently being used.

Solution

$N = ?$

$D = 100$ parts per hour

$T = 90$ minutes (1.5 hours)

$C = 84$ parts

$X = .10$

$$N = \frac{D(T)(1+X)}{C} = \frac{100(1.5)(1+.10)}{84} = 1.96 \text{ (round to 2) containers}$$

Problem 2

Determine the number of cycles per day and the production quantity per cycle for this set of products. The department operates five days a week. Assume the sequence A-B-C-D will be used.

Product	Weekly Quantity
A	20
B	40
C	30
D	15

Solution

Convert weekly quantities to daily quantities. The smallest *daily* quantity is 3 units. Producing in multiples of 3 units leaves A and B a few units short:

Product	Daily Quantity = Weekly Quantity ÷ 5	Units Short Using 3 Cycles
A	20 ÷ 5 = 4	1
B	40 ÷ 5 = 8	2
C	30 ÷ 5 = 6	—
D	15 ÷ 5 = 3	—

Use three cycles, producing all four products in every cycle. Produce units that are short by adding units to some cycles. Disperse the additional units as evenly as possible. There are several possibilities. One is

Cycle	1	2	3
Pattern	A B(3) C(2) D	A B(3) C(2) D	A(2) B(2) C(2) D
Extra unit(s)	B	B	A

DISCUSSION AND REVIEW QUESTIONS

1. Some key elements of production systems are listed in Table 14.3. Explain briefly how JIT systems differ from traditional production systems for each of those elements.
2. What is the ultimate goal of a JIT system? What are the supporting goals? What are the building blocks?
3. Describe the philosophy that underlies JIT (i.e., what is JIT intended to accomplish?).
4. What are some of the main obstacles that must be overcome in converting from a traditional system to JIT?
5. Briefly discuss vendor relations in JIT systems in terms of the following issues:
   a. Why are they important?
   b. How do they tend to differ from the more adversarial relations of the past?
   c. Why might suppliers be hesitant about JIT purchasing?
6. Certain Japanese have claimed that Henry Ford's assembly line provided some of the rationale for JIT. What features of assembly lines are common to JIT systems?
7. What is the kanban aspect of a JIT system?
8. Contrast push and pull methods of moving goods and materials through production systems.
9. What are the main benefits of a JIT system?
10. What is the hidden factory, and how does JIT eliminate most of it?
11. What are the benefits of small lot sizes?

TAKING STOCK

1. What trade-offs are involved in shifting from a traditional operations system to a JIT/lean system for:
   a. a manufacturing firm?
   b. a service firm?
2. Who in the organization is affected by a decision to shift from a traditional operations system to a JIT/lean system?
3. To what extent has technology had an impact on JIT/lean systems?

CRITICAL THINKING EXERCISE

In operations management, as in life, a balanced approach is often the best policy. One of the best examples of the benefits of this in operations management is the JIT/lean approach. Explain the basic factors that must be in place in order to achieve a balanced JIT/lean system.

PROBLEMS

1. A manager wants to determine the number of containers to use for incoming parts for a kanban system to be installed next month. The process will have a usage rate of 80 pieces per hour. Because the process is new, the manager has assigned an inefficiency factor of .35. Each container holds 45 pieces and it takes an average of 75 minutes to complete a cycle. How many containers should be used? As the system improves, will more or fewer containers be required? Why?
2. A JIT system uses kanban cards to authorize movement of incoming parts. In one portion of the system, a work center uses an average of 100 parts per hour while running. The manager has assigned an inefficiency factor of .20 to the center. Standard containers are designed to hold six dozen parts each. The cycle time for parts containers is about 105 minutes. How many containers are needed?
3. A machine cell uses 200 pounds of a certain material each day. Material is transported in vats that hold 20 pounds each. Cycle time for the vats is about two hours. The manager has assigned an inefficiency factor of .08 to the cell. The plant operates on an eight-hour day. How many vats will be used?
4. Determine the number of cycles per day and the production quantity per cycle for this set of products:

Product	Daily Quantity
A	21
B	12
C	3
D	15

   Use the sequence A-B-C-D.

5. Determine the number of cycles per day and a production quantity per cycle for this set of products that achieves fairly level production:

Product	Daily Quantity
A	22
B	12
C	4
D	15
E	9

   Assume the production sequence will be A-B-C-D-E.

6. Determine the number of cycles per day and a production quantity per cycle for this set of products that achieves fairly level production:

Product	Daily Quantity
F	9
G	8
H	5
K	6

   Assume the production sequence will be F-G-H-K.

Level Operations

CASE

Level Operations is a small company located in eastern Pennsylvania. It produces a variety of security devices and safes. The safes come in several different designs. Recently, a number of new customers have placed orders, and the production facility has been enlarged to accommodate increased demand for safes. Production manager Stephanie Coles is currently working on a production plan for the safes. She needs a plan for each day of the week. She has obtained the following infor-

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mation from the marketing department on projected demand for the next five weeks:

Model	Weekly Quantity
S1	120
S2	102
S7	48
S8	90
S9	25

The department operates five days a week. One complexity is that partially completed safes are not permitted; each cycle must turn out finished units.

After discussions with engineering, Stephanie determined that the best production sequence for each cycle is S7-S8-S9-S1-S2.

Question

What might Stephanie determine as the best production quantity per cycle for each day of the week?

Boeing

OPERATIONS TOUR

www.boeing.com

The Boeing Company, headquartered in Chicago, Illinois, is one of the two major producers of aircraft in the global market. The other major producer is European Airbus.

Boeing produces three models in Everett, Washington: 747s, 767s, and 777s. The planes are all produced in the same building. At any one time, there may be as many as six planes in various stages of production. Obviously the building has to be fairly large to accommodate such a huge undertaking. In fact, the building is so large that it covers over 98 acres and it is four stories high, making it the largest building by volume in the world. It is so large that all of Disneyland would fit inside, and still leave about 15 acres for indoor parking! The windowless building has six huge doors along one side, each about 100 yards wide and 40 yards high (the size of a football field)—large enough to allow a completed airplane to pass through.

Boeing sells airplanes to airlines and countries around the globe. There isn't a set price for the planes; the actual price depends on what features the customer wants. Once the details have been settled and an order submitted, the customer requirements are sent to the design department.

Design

Designers formerly had to construct a mockup to determine the exact dimensions of the plane and to identify any assembly problems that might occur. That required time, materials, labor, and space. Now they use computers (CAD) to design airplanes, avoiding the cost of the mockups and shortening the development time.

The Production Process

Once designs have been completed and approved by the customer, production of the plane is scheduled, and parts and materials are ordered. Parts come to the plant by rail, airplane, and truck, and are delivered to the major assembly area of the plane they will be used for. The parts are scheduled so they arrive at the plant just prior to when they will be used in assembly, and immediately moved to storage areas close to where they will be used. Time-phasing shipments to arrive as parts are needed helps to keep inventory investment low and avoids having to devote space to store parts that won't be used immediately. There is a trade-off, though, because if any parts are missing or damaged and have to be reordered, that could cause production delays. When missing or defective parts are discovered, they are assigned priorities according to how critical the part is in terms of disruption of the flow of work. The parts with the highest priorities are assigned to expediters who determine the best way to replace the part. The expediters keep track of the progress of the parts and deliver them to the appropriate location as soon as they arrive. In the meantime, a portion of the work remains unfinished, awaiting the replacement parts, and workers complete other portions of the assembly. If the supplier is unable to replace the part in a time frame that will not seriously delay assembly, as a last resort, Boeing has a machine shop that can make the necessary part.

The partially assembled portions of the plane, and in later stages, the plane itself, move from station to station as the work progresses, staying about five days at each station. Giant overhead cranes are used to move large sections from one station to the next, although once the wheel assemblies have been installed, the plane is towed to the remaining stations.

Finished planes are painted in one of two separate buildings. Painting usually adds 400 to 600 pounds to the weight of a plane. The painting process involves giving the airplane a negative charge and the paint a positive charge so that the paint will be attracted to the airplane.

Testing and Quality Control

Boeing has extensive quality control measures in place throughout the entire design and production process. Not only are there quality inspectors, individual employees inspect their own work

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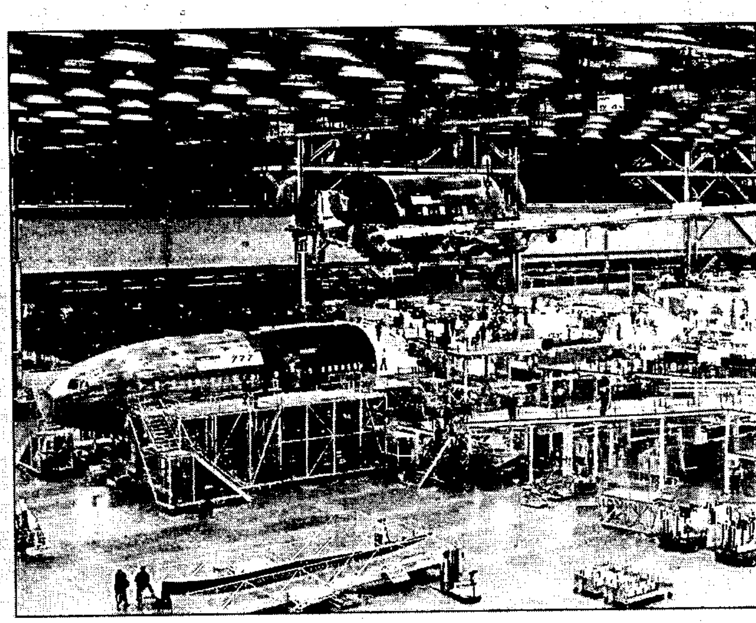
and the work previously done by others on the plane. Buyers' inspectors also check on the quality of the work.

There are 60 test pilots who fly the planes. Formerly planes were tested to evaluate their flight worthiness in a wind tunnel, which required expensive testing and added considerably to product development time. Now new designs are tested using a computerized wind tunnel before production even begins, greatly reducing both time and cost. And in case you're wondering, the wings are fairly flexible; a typical wing can flap by as much as 22 feet before it will fracture.



Wing and a portion of the fuselage being lowered into the plane.

Re-engineering

Boeing is re-engineering its business systems. A top priority is to upgrade its computer systems. This will provide better links to suppliers, provide more up-to-date information for materials management, and enable company representatives who are at customer sites to create a customized aircraft design on their laptop computer.

Another aspect of the re-engineering involves a shift to lean production. Key goals are to reduce production time and reduce inventory.

Boeing wants to reduce the time that a plane spends at each work station from 5 days to 3 days, a reduction of 40 percent. Not only will that mean that customers can get their planes much sooner, it will also reduce labor costs and inventory costs, and improve cash flow. One part of this will be accomplished by moving toward late stage customization, or delayed differentiation. That would mean standardizing the assembly of planes as long as possible before adding custom features. This, and other time-saving steps, will speed up production considerably, giving it a major competitive advantage. It also wants to reduce the tremendous amount of inventory it carries (a 747 jumbo jet has about 6 million parts, including 3 million rivets). One part of the plan is to have suppliers do more predelivery work by assembling the parts into kits that are delivered directly to the staging area where they will be installed on the aircraft instead of delivering separate parts to inventory. That would cut down on inventory carrying costs and save time.

Boeing is also hoping to reduce the number of suppliers it has, and to establish better links and cooperation from suppliers. Currently Boeing has about 3,500 suppliers. Compare that with GM's roughly 2,500 suppliers, and you get an idea of how large this number is.

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Supplement to

CHAPTER 14

Maintenance

LEARNING OBJECTIVES

After completing this supplement, you should be able to:

1 Explain the importance of maintenance in production systems.

2 Describe the range of maintenance activities.

3 Discuss preventive maintenance and the key issues associated with it.

4 Discuss breakdown maintenance and the key issues associated with it.

5 State how the Pareto phenomenon pertains to maintenance decisions.

SUPPLEMENT OUTLINE

maintenance All activities that maintain facilities and equipment in good working order so that a system can perform as intended.

Maintaining the production capability of an organization is an important function in any production system. **Maintenance** encompasses all those activities that relate to keeping facilities and equipment in good working order and making necessary repairs when breakdowns occur, so that the system can perform as intended.

Maintenance activities are often organized into two categories: (1) buildings and grounds and (2) equipment maintenance. Buildings and grounds is responsible for the appearance and functioning of buildings, parking lots, lawns, fences, and the like. Equipment maintenance is responsible for maintaining machinery and equipment in good working condition and making all necessary repairs.

INTRODUCTION

The goal of maintenance is to keep the production system in good working order at minimal cost. There are several reasons for wanting to keep equipment and machines in good operating condition, such as to

1. Avoid production or service disruptions.
2. Not add to production or service costs.
3. Maintain high quality.
4. Avoid missed delivery dates.

When breakdowns occur, there are a number of adverse consequences:

1. Operations capacity is reduced, and orders are delayed.
2. There is no output, but overhead continues, increasing the cost per unit.
3. There are quality issues; output may be damaged.
4. There are safety issues; employees or customers may be injured.

Decision makers have two basic options with respect to maintenance. One option is *reactive:* It is to deal with breakdowns or other problems when they occur. This is referred to as **breakdown maintenance.** The other option is *proactive:* It is to reduce breakdowns through a program of lubrication, adjustment, cleaning, inspection, and replacement of worn parts. This is referred to as **preventive maintenance.**

breakdown maintenance Reactive approach; dealing with breakdowns or problems when they occur.

preventive maintenance Proactive approach; reducing breakdowns through a program of lubrication, adjustment, cleaning, inspection, and replacement of worn parts.

Decision makers try to make a trade-off between these two basic options that will minimize their combined cost. With no preventive maintenance, breakdown and repair costs would be tremendous. Furthermore, hidden costs, such as lost output and the cost of wages while equipment is not in service, must be factored in. So must the cost of injuries or damage to other equipment and facilities or to other units in production. However, beyond a certain point, the cost of preventive maintenance activities exceeds the benefit.

As an example, if a person never had the oil changed in his or her car, never had it lubricated, and never had the brakes or tires inspected, but simply had repairs done when absolutely necessary, preventive costs would be negligible but repair costs would be quite high, considering the wide range of parts (engine, steering, transmission, tires, brakes, etc.) that could fail. In addition, property damage and injury costs might be incurred, plus there would be the uncertainty of when failure might occur (e.g., on the expressway during rush hour, or late at night). On the other hand, having the oil changed and the car lubricated every morning would obviously be excessive because automobiles are designed to perform for much longer periods without oil changes and lubrications. The best approach is to seek a balance between preventive maintenance and breakdown maintenance. The same concept applies to maintaining production systems: Strike a balance between prevention costs and breakdown costs. This concept is illustrated in Figure 14S.1.

The age and condition of facilities and equipment, the degree of technology involved, the type of production process, and similar factors enter into the decision of how much preventive maintenance is desirable. Thus, in the example of a new automobile, little preventive maintenance may be needed since there is slight risk of breakdowns. As the car ages and becomes worn through use, the desirability of preventive maintenance increases because the risk of breakdown increases. Thus, when tires and brakes begin to show signs of wear, they should be replaced before they fail; dents and scratches should be periodically taken care of before they

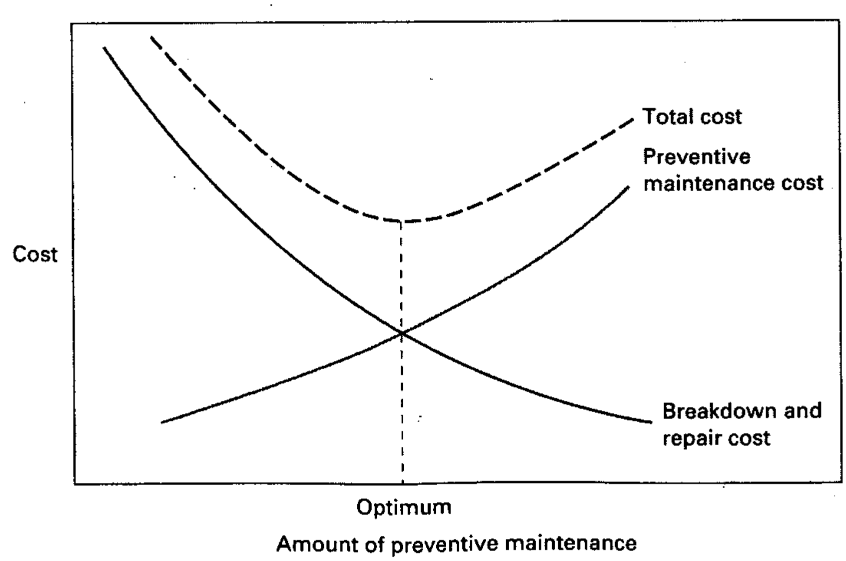

FIGURE 14S.1

Total maintenance cost as a function of preventive maintenance effort begin to rust; and the car should be lubricated and have its oil changed after exposure to high levels of dust and dirt. Also, inspection and replacement of critical parts that tend to fail suddenly should be performed before a road trip to avoid disruption of the trip and costly emergency repair bills.

PREVENTIVE MAINTENANCE

The goal of preventive maintenance is to reduce the incidence of breakdowns or failures in the plant or equipment to avoid the associated costs. Those costs can include loss of output; idle workers; schedule disruptions; injuries; damage to other equipment, products, or facilities; and repairs, which may involve maintaining inventories of spare parts, repair tools and equipment, and repair specialists.

Preventive maintenance is *periodic*. It can be scheduled according to the availability of maintenance personnel and to avoid interference with operating schedules. Managers usually schedule preventive maintenance using some combination of the following:

1. The result of planned inspections that reveal a need for maintenance.
2. According to the calendar (passage of time).
3. After a predetermined number of operating hours.

An important issue in preventive maintenance is the frequency of preventive maintenance. As the time between periodic maintenance increases, the cost of preventive maintenance decreases while the risk (and cost) of breakdowns increases. As noted, the goal is to strike a balance between the two costs (i.e., to minimize total cost).

Determining the amount of preventive maintenance to use is a function of the expected frequency of breakdown, the cost of a breakdown (including actual repair costs as well as potential damage or injury, lost production, and so on). The following two examples illustrate this.

EXAMPLE S-1

The frequency of breakdown of a machine per month is shown in the table. The cost of a breakdown is $1,000 and the cost of preventive maintenance is $1,250 per month. If preventive maintenance is performed, the probability of a machine breakdown is negligible. Should the manager use preventive maintenance, or would it be cheaper to repair the machine when it breaks down?

Number of breakdowns	0	1	2	3
Frequency of occurrence	.20	.30	.40	.10

SOLUTION

The expected number of breakdowns without preventive maintenance is 1.40:

Number of Breakdowns	×	Frequency of Occurrence	=	Expected Number of Breakdowns
0		.20		0
1		.30		.30
2		.40		.80
3		.10		.30
		1.00		1.40

Expected cost using repair policy is 1.40 breakdowns/month × $1,000/breakdown = $1,400. Preventive maintenance would cost $1,250.

Therefore, preventive maintenance would yield a savings of $150/month.

EXAMPLE S-2

Another approach that might be used relates to the time before a breakdown occurs. Suppose that the average time before breakdown is normally distributed and has a mean of 3 weeks and a standard deviation of .60 week. If breakdown cost averages $1,000 and preventive maintenance costs $250, what is the optimal maintenance interval?

SOLUTION

Begin by computing the ratio of preventive cost to the sum of preventive and breakdown cost:

$$\frac{\text{Preventive cost}}{\text{Preventive cost} + \text{Breakdown cost}} = \frac{\$250}{\$250 + \$1{,}000} = .20$$

Find the number of standard deviations from the mean represented by an area under the normal curve equal to .20 using Appendix B, Table B. It is -0.84. Use this value of z to compute the maintenance interval:

$$\text{Mean} + z \text{ standard deviations} = 3 - .84(.60) = 2.496 \text{ (round to } 2\tfrac{1}{2} \text{ weeks)}$$

Ideally, preventive maintenance will be performed just prior to a breakdown or failure because this will result in the longest possible use of facilities or equipment without a breakdown. **Predictive maintenance** is an attempt to determine when to perform preventive maintenance activities. It is based on historical records and analysis of technical data to predict when a piece of equipment or part is about to fail. The better the predictions of failures are, the more effective preventive maintenance will be. A good preventive maintenance effort relies on complete records for each piece of equipment. Records must include information such as date of installation, operating hours, dates and types of insurance, and dates and types of repairs.

predictive maintenance An attempt to determine when best to perform preventive maintenance activities.

Some companies have workers perform preventive maintenance on the machines they operate, rather than use separate maintenance personnel for that task. Called **total productive maintenance,** this approach is consistent with JIT systems and lean operations, where employees are given greater responsibility for quality, productivity, and the general functioning of the system.

total productive maintenance JIT approach where workers perform preventive maintenance on the machines they operate.

In the broadest sense, preventive maintenance extends back to the design and selection stage of equipment and facilities. Maintenance problems are sometimes *designed into* a system. For example, equipment may be designed in such a way that it needs frequent maintenance, or maintenance may be difficult to perform (e.g., the equipment has to be partially dismantled in order to perform routine maintenance). An extreme example of this was a certain car model that required the engine block to be lifted slightly in order to change the spark plugs! In such cases, it is very likely that maintenance will be performed less often than if its performance was less demanding. In other instances, poor design can cause equipment to wear out at an early age or experience a much higher than expected breakdown rate. *Consumer Reports,* for example, publishes annual breakdown data on automobiles. The data indicate that some models tend to break down with a much higher frequency than other models.

One possible reason for maintenance problems being designed into a product is that designers have accorded other aspects of design greater importance. Cost is one such aspect. Another is appearance; an attractive design may be chosen over a less attractive one even though it will be more demanding to maintain. Customers may contribute to this situation; the buying public probably has a greater tendency to select an attractive design over one that offers ease of maintenance.

Obviously, durability and ease of maintenance can have long-term implications for preventive maintenance programs. Training of employees in proper operating procedures and in how to keep equipment in good operating order—and providing the incentive to do so—are also important. More and more, U.S. organizations are taking a cue from the Japanese and transferring routine maintenance (e.g., cleaning, adjusting, inspecting) to the users of equipment, in an effort to give them a sense of responsibility and awareness of the equipment they use and to cut down on abuse and misuse of the equipment.

BREAKDOWN PROGRAMS

The risk of a breakdown can be greatly reduced by an effective preventive maintenance program. Nonetheless, occasional breakdowns still occur. Even firms with good preventive practices have some need for breakdown programs. Of course, organizations that rely less on preventive maintenance have an even greater need for effective ways of dealing with breakdowns.

Unlike preventive maintenance, management cannot schedule breakdowns but must deal with them on an irregular basis (i.e., as they occur). Among the major approaches used to deal with breakdowns are the following:

1. *Standby or backup equipment* that can be quickly pressed into service.
2. *Inventories of spare parts* that can be installed as needed, thereby avoiding lead times involved in ordering parts, and *buffer inventories,* so that other equipment will be less likely to be affected by short-term downtime of a particular piece of equipment.
3. *Operators* who are able to perform at least minor repairs on their equipment.
4. *Repair people* who are well trained and readily available to diagnose and correct problems with equipment.

The degree to which an organization pursues any or all of these approaches depends on how important a particular piece of equipment is to the overall operations system. At one extreme is equipment that is the focal point of a system (e.g., printing presses for a newspaper, or vital operating parts of a car, such as brakes, steering, transmission, ignition, and engine). At the other extreme is equipment that is seldom used because it does not perform an important function in the system, and equipment for which substitutes are readily available.

The implication is clear: Breakdown programs are most effective when they take into account the degree of importance a piece of equipment has in the operations system, and the ability of the system to do without it for a period of time. The Pareto phenomenon exists in such situations: A relatively few pieces of equipment will be extremely important to the functioning of the system, thereby justifying considerable effort and/or expense; some will require moderate effort or expense; and many will justify little effort or expense.

REPLACEMENT

When breakdowns become frequent and/or costly, the manager is faced with a trade-off decision in which costs are an important consideration: What is the cost of replacement compared with the cost of continued maintenance? This question is sometimes difficult to resolve, especially if future breakdowns cannot be readily predicted. Historical records may help to project future experience. Another factor is technological change; newer equipment may have features that favor replacement over either preventive or breakdown maintenance. On the other hand, the removal of old equipment and the installation of new equipment may cause disruptions to the system, perhaps greater than the disruptions caused by breakdowns. Also, employees may have to be trained to operate the new equipment. Finally, forecasts of future demand for the use of the present or new equipment must be taken into account. The demand for the replacement equipment might differ because of the different features it has. For instance, demand for output of the current equipment might be two years, while demand for output of the replacement equipment might be much longer.

These decisions can be fairly complex, involving a number of different factors. Nevertheless, most of us are faced with a similar decision with our personal automobiles: When is it time for a replacement?

SUMMARY

Maintaining the productive capability of an organization is an important function. Maintenance includes all of the activities related to keeping facilities and equipment in good operating order and maintaining the appearance of buildings and grounds.

The goal of maintenance is to minimize the total cost of keeping the facilities and equipment in good working order. Maintenance decisions typically reflect a trade-off between preventive maintenance, which seeks to reduce the incidence of breakdowns and failures, and breakdown maintenance, which seeks to reduce the impact of breakdowns when they do occur.

KEY TERMS

breakdown maintenance, 649
maintenance, 648
predictive maintenance, 651
preventive maintenance, 649
total productive maintenance, 651

DISCUSSION AND REVIEW QUESTIONS

1. What is the goal of a maintenance program?
2. List the costs associated with equipment breakdown.
3. What are three different ways preventive maintenance is scheduled?
4. Explain the term *predictive maintenance* and the importance of good records.
5. List the major approaches organizations use to deal with breakdowns.
6. Explain how the Pareto phenomenon applies to
   a. Preventive maintenance.
   b. Breakdown maintenance.
7. Discuss the key points of this supplement as they relate to maintenance of an automobile.
8. What advantages does preventive maintenance have over breakdown maintenance?
9. Explain why having a good preventive maintenance program in place is necessary prior to implementing a JIT system.
10. Discuss the relationship between preventive maintenance and quality.

PROBLEMS

1. The probability that equipment used in a hospital lab will need recalibration is given in the following table. A service firm is willing to provide maintenance and provide any necessary calibrations for free for a fee of $650 per month. Recalibration costs $500 per time. Which approach would be most cost-effective, recalibration as needed or the service contract?

Number of Recalibrations	0	1	2	3	4
Probability of Occurrence	.15	.25	.30	.20	.10

2. The frequency of breakdown of a machine that issues lottery tickets is given in the following table. Repairs cost an average of $240. A service firm is willing to provide preventive maintenance under either of two options. #1 is $500 and covers all necessary repairs, and #2 is $350 and covers any repairs after the first one. Which option would have the lowest expected cost, pay for all repairs, service option #1, or service option #2?

Number of Breakdowns/Month	0	1	2	3	4
Frequency of Occurrence	.10	.30	.30	.20	.10

3. Determine the optimum preventive maintenance frequency for each of the pieces of equipment if breakdown time is normally distributed:

Equipment	Average Time (days) between Breakdowns	Standard Deviation
A201	20	2
B400	30	3
C850	40	4

Equipment	Preventive Maintenance Cost	Breakdown Cost
A201	$300	$2,300
B400	$200	$3,500
C850	$530	$4,800

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CHAPTER 15

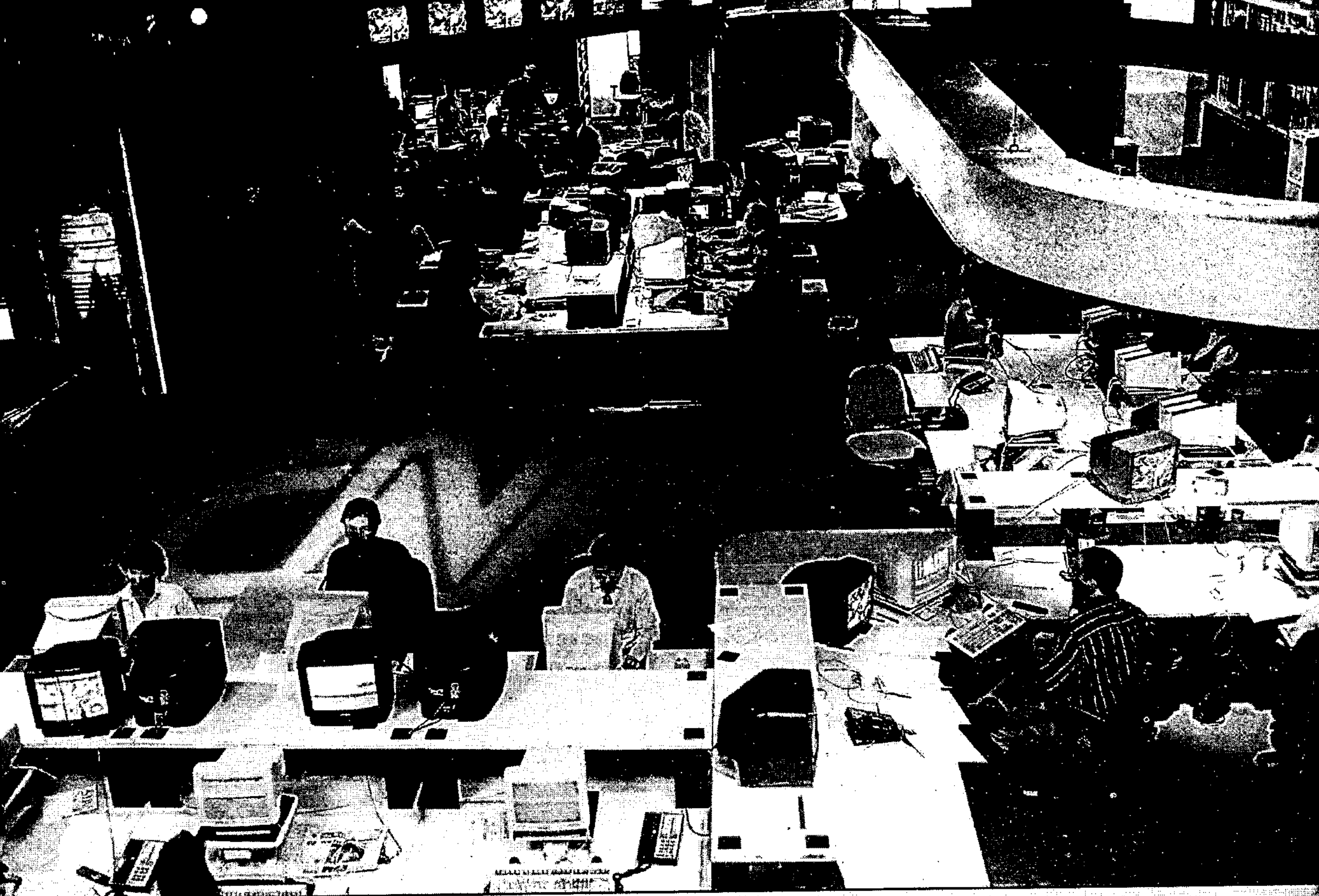
Scheduling

LEARNING OBJECTIVES

After completing this chapter, you should be able to:

1. Explain what scheduling involves and the importance of good scheduling.
2. Discuss scheduling needs in high-volume and intermediate-volume systems.
3. Discuss scheduling needs in job shops.
4. Use and interpret Gantt charts, and use the assignment method for loading.
5. Discuss and give examples of commonly used priority rules.
6. Describe some of the unique problems encountered in service systems, and describe some of the approaches used for scheduling service systems.

CHAPTER OUTLINE



Within an organization, **scheduling** pertains to establishing the timing of the use of specific resources of that organization. It relates to the use of equipment, facilities, and human activities. Scheduling occurs in every organization, regardless of the nature of its activities. For example, manufacturers must schedule production, which means developing schedules for workers, equipment, purchases, maintenance, and so on. Hospitals must schedule admissions, surgery, nursing assignments, and support services such as meal preparation, security, maintenance, and cleaning. Educational institutions must schedule classrooms, instruction, and students. And lawyers, doctors, dentists, hairdressers, and auto repair shops must schedule appointments.

scheduling Establishing the timing of the use of equipment, facilities, and human activities in an organization.

IS

In the decision-making hierarchy, scheduling decisions are the final step in the transformation process before actual output occurs. Many decisions about system design and operation have been made long before scheduling decisions. They include the capacity of the system, equipment selection, selection and training of workers, and design of products and services. Consequently, scheduling decisions must be made within the constraints established by many other decisions, making them fairly narrow in scope and latitude.

Effective scheduling can yield cost savings and increases in productivity. It also can yield other benefits. For example, in hospitals, effective scheduling can save lives and improve patient care. In educational institutions, it can reduce the need for expansion of facilities. In competitive environments, effective scheduling can give a company a competitive advantage in terms of customer service (shorter wait time for their orders) if its competitors are less effective with their scheduling.

Generally, the objectives of scheduling are to achieve trade-offs among conflicting goals, which include efficient utilization of staff, equipment, and facilities, and minimization of customer waiting time, inventories, and process times.

This chapter covers scheduling in both manufacturing and service environments. Although the two environments have many similarities, some basic differences are important.

SCHEDULING OPERATIONS

Scheduling tasks are largely a function of the volume of system output. High-volume systems require approaches substantially different from those required by job shops, and project scheduling requires still different approaches. In this chapter, we will consider scheduling for high-volume systems, intermediate-volume systems, and low-volume (job shop) scheduling. Project scheduling is discussed in Chapter 17.

Scheduling in High-Volume Systems

flow system High-volume system with standardized equipment and activities.

flow-shop scheduling Scheduling for flow systems.

Scheduling encompasses allocating workloads to specific work centers and determining the sequence in which operations are to be performed. High-volume systems are characterized by standardized equipment and activities that provide identical or highly similar operations on customers or products as they pass through the system. The goal is to obtain a smooth rate of flow of goods or customers through the system in order to get a high utilization of labor and equipment. High-volume systems are often referred to as **flow systems;** scheduling in these systems is referred to as **flow-shop scheduling,** although flow-shop scheduling also can be used in medium-volume systems. Examples of high-volume products include autos, personal computers, radios and televisions, stereo equipment, toys, and appliances. In process industries, examples include petroleum refining, sugar refining, mining, waste treatment, and the manufacturing of fertilizers. Examples of services include cafeteria lines, news broadcasts, and mass inoculations. Because of the highly repetitive nature of these systems, many of the loading and sequence decisions are determined during the design of the system. The use of highly specialized tools and equipment, the arrangement of equipment, the use of specialized material-handling equipment, and the division of labor are all designed to enhance the flow of work through the system, since all items follow virtually the same sequence of operations.

A major aspect in the design of flow systems is *line balancing,* which concerns allocating the required tasks to workstations so that they satisfy technical (sequencing) constraints and are balanced with respect to equal work times among stations. Highly balanced systems result in the maximum utilization of equipment and personnel as well as the highest possible rate of output. Line balancing is discussed in Chapter 6.

In setting up flow systems, designers must consider the potential discontent of workers in connection with the specialization of job tasks in these systems; high work rates are often achieved by dividing the work into a series of relatively simple tasks assigned to different workers. The resulting jobs tend to be boring and monotonous and may give rise to fatigue, absenteeism, turnover, and other problems, all of which tend to reduce productivity and disrupt the smooth flow of work. These problems and potential solutions are elaborated on in Chapter 7, which deals with the design of work systems.

In spite of the built-in attributes of flow systems related to scheduling, a number of scheduling problems remain. One stems from the fact that few flow systems are *completely* devoted to a single product or service; most must handle a variety of sizes and models. Thus, an automobile manufacturer will assemble many different combinations of cars—two-door and four-door models, some with air-conditioning and some not, some with deluxe trim and others with standard trim, some with CD players, some with tinted glass, and so on. The same can be said for producers of appliances, electronic equipment, and toys. Each change involves slightly different inputs of parts, materials, and processing requirements that must be scheduled into the line. If the line is to operate smoothly, a supervisor must coordinate the flow of materials and the work, which includes the inputs, the processing, and the outputs, as well as purchases.

In addition to achieving a smooth flow, it is important to avoid excessive buildup of inventories. Again, each variation in size or model will tend to have somewhat different inventory requirements, so that additional scheduling efforts will be needed.

One source of scheduling concern is possible disruptions in the system that result in less than the desired output. These can be caused by equipment failures, material shortages, accidents, and absences. In practice, it is usually impossible to increase the rate of output to compensate for these factors, mainly because flow systems are designed to operate at a given rate. Instead, strategies involving subcontracting or overtime are often required, although subcontracting on short notice is not always feasible. Sometimes work that is partly completed can be made up off the line.

The reverse situation can also impose scheduling problems although these are less severe. This happens when the desired output is less than the usual rate. However, instead of slowing the ensuing rate of output, it is usually necessary to operate the system at the usual rate, but for fewer hours. For instance, a production line might operate temporarily for seven hours a day instead of eight.

High-volume systems usually require automated or specialized equipment for processing and handling. Moreover, they perform best with a high, uniform output. Consequently, the following factors often determine the success of such a system:

1. *Process and product design.* Here, cost and manufacturability are important, as is achieving a smooth flow through the system.
2. *Preventive maintenance.* Keeping equipment in good operating order can minimize breakdowns that would disrupt the flow of work.
3. *Rapid repair when breakdowns occur.* This can require specialists as well as stocks of critical spare parts.
4. *Optimal product mixes.* Techniques such as linear programming can be used to determine optimal blends of inputs to achieve desired outputs at minimal costs. This is particularly true in the manufacture of fertilizers, animal feeds, and diet foods.
5. *Minimization of quality problems.* Quality problems can be extremely disruptive, requiring shutdowns while problems are resolved. Moreover, when output fails to meet quality standards, not only is there the loss of output but also a waste of the labor, material, time, and other resources that went into it.
6. *Reliability and timing of supplies.* Shortages of supplies are an obvious source of disruption and must be avoided. On the other hand, if the solution is to stockpile supplies, that can lead to high carrying costs. Shortening supply lead times, developing reliable supply schedules, and carefully projecting needs are all useful.

Scheduling in Intermediate-Volume Systems

Intermediate-volume system outputs fall between the standardized type of output of the high-volume systems and made-to-order output of job shops. Like the high-volume systems, intermediate-volume systems typically produce standard outputs. If manufacturing is involved, the products may be for stock rather than for special order. However, the volume of output in such cases is not large enough to justify continuous production. Instead, it is more economical to process these items *intermittently.* Thus, intermediate-volume work centers periodically shift from one job to another. In contrast to a job shop, the run sizes are relatively large. Examples of products made in these systems include canned foods, baked goods, paint, and cosmetics.

The three basic issues in these systems are the *run size* of jobs, the *timing* of jobs, and the *sequence* in which jobs should be processed.

Sometimes, the issue of run size can be determined by using a model such as the economic run size model discussed in Chapter 11 on inventory management. The run size that would minimize setup and inventory costs is

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$$Q_0 = \sqrt{\frac{2DS}{H}}\sqrt{\frac{p}{p-u}} \qquad (15\text{–}1)$$

Setup cost may be an important consideration. For one thing, setup costs may depend on the order in which jobs are processed; similar jobs may require less setup change between them. For example, jobs in a print shop may be sequenced by ink color to reduce the number of setups needed. This opens up the possibility of reducing setup cost and time by taking processing sequence into account. It also makes sequencing more complex, and it requires estimating job setup costs for every sequence combination.

In another vein, companies are working to reduce setup times and, hence, experience less downtime for equipment changeover. Tactics include off-line setups, snap-on parts, modular setups, and flexible equipment designed to handle a variety of processing requirements.

Another difficulty arises because usage is not always as smooth as assumed in the model. Some products will tend to be used up faster than expected and have to be replenished sooner. Also, because multiple products are to be processed, it is not always possible to schedule production to correspond with optimum run intervals.

Another approach frequently used is to base production on a master schedule developed from customer orders and forecasts of demand. Companies engaged in assembly operations would then use an MRP approach (described in Chapter 13 to determine the quantity and projected timing of jobs for components. The manager would then compare projected requirements with projected capacity and develop a feasible schedule from that information. Companies engaged in producing processed rather than assembled goods (e.g., food products, such as canned goods and beverages; publishing, such as magazines; paints and cleaning supplies) would use a somewhat different approach; the *time-phasing* information provided by MRP would not be an important factor.

SCHEDULING IN LOW-VOLUME SYSTEMS

job-shop scheduling Scheduling for low-volume systems with many variations in requirements.

The characteristics of low-volume systems (job shops) are considerably different from those of high- and intermediate-volume systems. Products are made to order, and orders usually differ considerably in terms of processing requirements, materials needed, processing time, and processing sequence and setups. Because of these circumstances, **job-shop scheduling** is usually fairly complex. This is compounded by the impossibility of establishing firm schedules prior to receiving the actual job orders.

Job-shop processing gives rise to two basic issues for schedulers: how to distribute the workload among work centers and what job processing sequence to use.

Loading

loading The assignment of jobs to processing centers.

Loading refers to the assignment of jobs to processing (work) centers. Loading decisions involve assigning specific jobs to work centers and to various machines in the work centers. In cases where a job can be processed only by a specific center, loading presents little difficulty. However, problems arise when two or more jobs are to be processed and there are a number of work centers capable of performing the required work. In such cases, the operations manager needs some way of assigning jobs to the centers.

When making assignments, managers often seek an arrangement that will minimize processing and setup costs, minimize idle time among work centers, or minimize job completion time, depending on the situation.

Gantt chart Chart used as visual aid for loading and scheduling purposes.

Gantt Charts Visual aids called **Gantt charts** are used for a variety of purposes related to loading and scheduling. They derive their name from Henry Gantt, who pioneered the use of charts for industrial scheduling in the early 1900s. Gantt charts can be used in a number of different ways, two of which are illustrated in Figure 15.1, which shows scheduling classrooms for a university and scheduling hospital operating rooms for a day.

The purpose of Gantt charts is to organize and visually display the actual or intended use of resources in a *time framework*. In most cases, a time scale is represented horizontally, and resources to be scheduled are listed vertically. The use and idle times of resources are reflected in the chart.

Managers may use the charts for trial-and-error schedule development to get an idea of what different arrangements would involve. Thus, a tentative surgery schedule might reveal insufficient allowance for surgery that takes longer than expected and can be revised accordingly. Use of the chart for classroom scheduling would help avoid assigning two different classes to the same room at the same time.

There are a number of different types of Gantt charts. Two of the most commonly used are the *load chart* and the *schedule chart*.

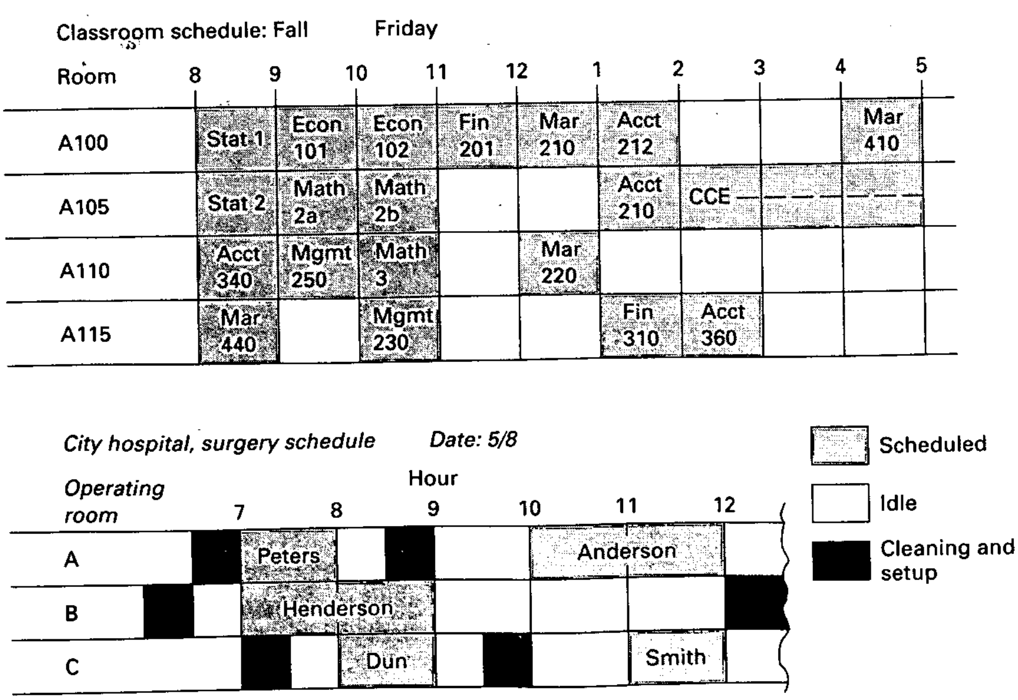


FIGURE 15.1

Examples of charts used for scheduling

FIGURE 15.2

A Gantt load chart

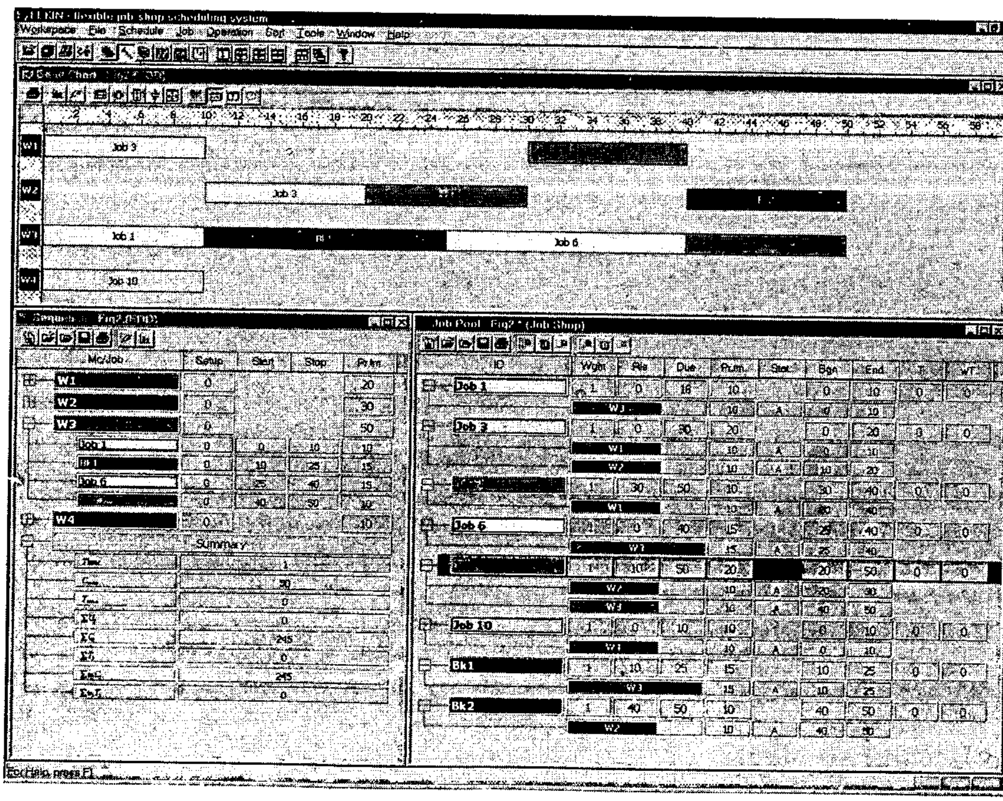
Work center	Mon.	Tues.	Wed.	Thurs.	Fri.
1	Job 3			Job 4	
2		Job 3	Job 7		X
3	Job 1	X	X / Job 6	Job 6	Job 7
4	Job 10				

☐ Processing

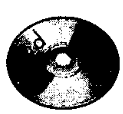
☒ Center not available (e.g., maintenance)

load chart A Gantt chart that shows the loading and idle times for a group of machines or list of departments.

A **load chart** depicts the loading and idle times for a group of machines or a list of departments. Figure 15.2 illustrates a typical load chart. This chart indicates that work center 3 is completely loaded for the entire week, center 4 will be available after noon on Tuesday, and the other two centers have idle time scattered throughout the week. This information can help a manager rework loading assignments to better utilize the centers. For instance, if all centers perform the same kind of work, the manager might want to free one center for a long job or a rush order. The chart also shows when certain jobs are scheduled to start and finish, and where to expect idle time.



The same Gantt chart using the Lekin software, included on your DVD. This software, developed at NYU, includes multiple scheduling routines along with graphics such as this interactive Gantt chart for scheduling a wide variety of manufacturing systems.



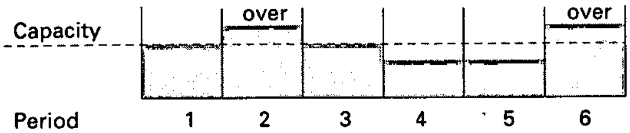
Scheduling Program

infinite loading Jobs are assigned to work centers without regard to the capacity of the work center.

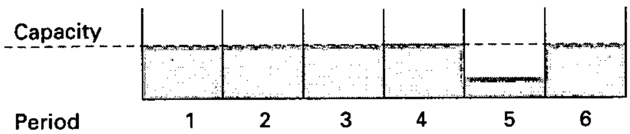
finite loading Jobs are assigned to work centers taking into account the work center capacity and job processing times.

Two different approaches are used to load work centers: *infinite* loading and *finite* loading. **Infinite loading** assigns jobs to work centers without regard to the capacity of the work center. As you can see in the diagram below, this can lead to overloads in some time periods and underloads in others. The priority sequencing rules described in this chapter use infinite loading. One possible result of infinite loading is the formation of queues in some (or all) work centers. **Finite loading** projects actual job starting and stopping times at each work center, taking into account the capacities of each work center and the processing times of jobs, so that capacity is not exceeded. One output of finite loading is a detailed projection of hours each work center will operate. Schedules based on finite loading may have to be updated often, perhaps daily, due to processing delays at work centers and the addition of new jobs or cancellation of current jobs. The following diagram illustrates these two approaches.

Infinite loading



Finite loading



With infinite loading, a manager may need to make some response to overloaded work centers. Among the possible responses are shifting work to other periods or other centers, working overtime, or contracting out a portion of the work. Note that the last two options in effect increase capacity to meet the work load.

Finite loading may reflect a fixed upper limit on capacity. For example, a bus line will have only so many buses. Hence, the decision to place into service a particular number of buses fixes capacity. Similarly, a manufacturer might have one specialized machine that it operates around the clock. Thus, it is operated at the upper limit of its capacity, so finite loading would be called for.

There are two general approaches to scheduling: forward scheduling and backward scheduling. **Forward scheduling** means scheduling ahead from a point in time; **backward scheduling** means scheduling backward from a due date. Forward scheduling is used if the issue is "How long will it take to complete this job?" Backward scheduling would be used if the issue is "When is the latest the job can be started and still be completed by the due date?"

forward scheduling Scheduling ahead, from some point in time.

backward scheduling Scheduling by working backwards from the due date(s).

A manager often uses a **schedule chart** to monitor the progress of jobs. The vertical axis on this type of Gantt chart shows the orders or jobs in progress, and the horizontal axis shows time. The chart indicates which jobs are on schedule and which are behind or ahead.

schedule chart A Gantt chart that shows the orders or jobs in progress and whether they are on schedule.

A typical schedule chart is illustrated in Figure 15.3. It shows the current status of a landscaping job with planned and actual starting and finishing times for the five stages of the job. The chart indicates that approval and the ordering of trees and shrubs was on schedule. The site preparation was a bit behind schedule. The trees were received earlier than expected, and planting is ahead of schedule. However, the shrubs have not yet been received. The chart indicates some slack between scheduled receipt of shrubs and shrub planting, so if the shrubs arrive by the end of the week, it appears the schedule can still be met.

Despite the obvious benefits of Gantt charts and the fact that they are widely used, they possess certain limitations, the chief one being the need to repeatedly update a chart to keep it current. In addition, a chart does not directly reveal costs associated with alternative loadings. Finally, a job's processing time may vary depending on the work center; certain stations or work centers may be capable of processing some jobs faster than other stations. Again, that situation would increase the complexity of evaluating alternative schedules.

In addition to Gantt charts, managers often rely on input/output reports to manage work flow.

Input/Output Control **Input/output (I/O) control** refers to monitoring the work flow and queue lengths at work centers. The purpose of I/O control is to manage work flow so that queues and waiting times are kept under control. Without I/O control, demand may exceed processing capacity, causing an overload at the center. Conversely, work may arrive slower than the rate a work center can handle, leaving the work center underutilized. Ideally, a balance can be struck between the input and output rates, thereby achieving effective use of work center capacities without experiencing excessive queues at the work centers. A simple example of I/O control is the use of stoplights on some expressway onramps. These regulate the flow of entering traffic according to the current volume of expressway traffic.

input/output (I/O) control Managing work flow and queues at work centers.

FIGURE 15.3

Progress chart for landscaping job

Stage	1	2	3	4	5	6	7
Drawings	[Approval]						
Site		[Preparation]					
Trees		[Order]		[Receive]	[Plant]		
Shrubs		[Order]			[Receive]	[Plant]	
Final Inspection							[Approval]

Scheduled [ ]

Now (stage 5)

Actual progress

FIGURE 15.4

A sample input/output report for a work center showing input and output in hours of processing time

		Period 1	2	3	4	5	6
Input	Planned	100	100	90	90	90	90
	Actual	120	95	80	88	93	94
	Deviation	+20	−5	−10	−2	+3	+4
	Cum. dev.	+20	+15	+5	+3	+6	+10
Output	Planned	110	110	100	100	100	95
	Actual	110	105	95	101	103	96
	Deviation	0	−5	−5	+1	+3	+1
	Cum. dev.	0	−5	−10	−9	−6	−5

Backlog	40*	50	40	25	12	2	0

Note: Figures represent standard hours of processing time.
*Given, not derived from the data.

Figure 15.4 illustrates an input/output report for a work center. A key portion of the report is the backlog of work waiting to be processed. The report reveals deviations-from-planned for both inputs and outputs, thereby enabling a manager to determine possible sources of problems.

The deviations in each period are determined by subtracting "planned" from "actual." For example, in the first period, subtracting the planned input of 100 hours from the actual input of 120 hours produces a deviation of +20 hours. Similarly, in the first period, the planned and actual outputs are equal, producing a deviation of 0 hours.

The backlog for each period is determined by subtracting the "actual output" from the "actual input" and adjusting the backlog from the previous period by that amount. For example, in the second period actual output exceeds actual input by 10 hours. Hence, the previous backlog of 50 hours is reduced by 10 hours to 40 hours.

Another approach that can be used to assign jobs to resources is the *assignment method.*

assignment model A linear programming model for optimal assignment of tasks and resources.

Assignment Method of Linear Programming The **assignment model** is a special-purpose linear programming model that is useful in situations that call for assigning tasks or other work requirements to resources. Typical examples include assigning jobs to machines or workers, territories to salespeople, and repair jobs to repair crews. The idea is to obtain an optimum *matching* of tasks and resources. Commonly used criteria include costs, profits, efficiency, and performance.

TABLE 15.1
A typical assignment problem

		MACHINE			
		A	B	C	D
Job	1	8	6	2	4
	2	6	7	11	10
	3	3	5	7	6
	4	5	10	12	9

Table 15.1 illustrates a typical problem, where four jobs are to be assigned to four machines. The problem is arranged in a format that facilitates evaluation of assignments. The numbers in the body of the table represent the value or cost associated with each job–machine combination. In this case, the numbers represent costs. Thus, it would cost $8 to do job 1 on machine A, $6 to do job 1 on machine B, and so on. If the problem involved minimizing the cost for job 1 alone, it would clearly be assigned to machine C, since that combination has the lowest cost. However, that assignment does not take into account the other jobs and their costs, which is important since the lowest-cost assignment for any one job may not be consistent with a minimum-cost assignment when all jobs are considered.

If there are to be n matches, there are $n!$ different possibilities. In this case, there are $4! = 24$ different matches. One approach is to investigate each match and select the one with the lowest cost. However, if there are 12 jobs, there would be 479 million different matches! A much simpler approach is to use a procedure called the **Hungarian method** to identify the lowest-cost solution.

Hungarian method Method of assigning jobs by a one-for-one matching to identify the lowest-cost solution.

To be able to use the Hungarian method, a one-for-one matching is required. Each job, for example, must be assigned to only one machine. It is also assumed that every machine is capable of handling every job, and that the costs or values associated with each assignment combination are known and fixed (i.e., not subject to variation). The number of rows and columns must be the same. Solved Problem 1 at the end of the chapter shows what to do if they aren't the same.

Once the relevant cost information has been acquired and arranged in tabular form, the basic procedure of the Hungarian method is

1. Subtract the smallest number in each row from every number in the row. This is called a *row reduction.* Enter the results in a new table.
2. Subtract the smallest number in each column of the new table from every number in the column. This is called a *column reduction.* Enter the results in another table.
3. Test whether an optimum assignment can be made. You do this by determining the *minimum* number of lines (horizontal or vertical) needed to cross out (cover) all zeros. If the number of lines equals the number of rows, an optimum assignment is possible. In that case, go to step 6. Otherwise go on to step 4.
4. If the number of lines is less than the number of rows, modify the table in this way:
   a. Subtract the smallest uncovered number from every uncovered number in the table.
   b. Add the smallest uncovered number to the numbers at *intersections* of cross-out lines.
   c. Numbers crossed out but not at intersections of cross-out lines carry over unchanged to the next table.
5. Repeat steps 3 and 4 until an optimal table is obtained.
6. Make the assignments. Begin with rows or columns with only one zero. Match items that have zeros, using only one match for each row and each column. Eliminate both the row and the column after the match.

EXAMPLE 1

Determine the optimum assignment of jobs to machines for the following data (from Table 15.1).

		MACHINE				
		A	B	C	D	Row Minimum
Job	1	8	6	2	4	2
	2	6	7	11	10	6
	3	3	5	7	6	3
	4	5	10	12	9	5

SOLUTION

a. Subtract the smallest number in each row from every number in the row, and enter the results in a new table. The result of this row reduction is

		MACHINE			
		A	B	C	D
Job	1	6	4	0	2
	2	0	1	5	4
	3	0	2	4	3
	4	0	5	7	4
Column Minimum		0	1	0	2

b. Subtract the smallest number in each column from every number in the column, and enter the results in a new table. The result of this column reduction is

		MACHINE			
		A	B	C	D
Job	1	6	3	0	0
	2	0	0	5	2
	3	0	1	4	1
	4	0	4	7	2

c. Determine the *minimum* number of lines needed to cross out all zeros. (Try to cross out as many zeros as possible when drawing lines.)

		Machine			
		A	*B*	*C*	*D*
Job	1	6	3	0	0
	2	0	0	5	2
	3	0	1	4	1
	4	0	4	7	2

d. Since only three lines are needed to cross out all zeros and the table has four rows, this is not the optimum. Note that the smallest uncovered value is 1.

e. Subtract the smallest uncovered value from every uncovered number that hasn't been crossed out, and add it to numbers that are at the intersections of covering lines. The results are

		MACHINE			
		A	B	C	D
Job	1	7	3	0	0
	2	1	0	5	2
	3	0	0	3	0
	4	0	3	6	1

f. Determine the minimum number of lines needed to cross out all zeros (four). Since this equals the number of rows, you can make the optimum assignment.

		Machine			
		A	*B*	*C*	*D*
Job	1	7	3	0	0
	2	1	0	5	2
	3	0	0	3	0
	4	0	3	6	1

g. Make assignments: Start with rows and columns with only one zero. Match jobs with machines that have a zero cost.

		Machine			
		A	*B*	*C*	*D*
Job	1	7	3	0	0
	2	1	0	5	2
	3	0	0	3	0
	4	0	3	6	1

Assignment	**Cost**
1–C	$ 2
2–B	7
3–D	6
4–A	5
	$20

As you can see, the progress is relatively simple. The simplicity of the Hungarian method belies its usefulness when the assumptions are met. Not only does it provide a rational method for making assignments, it guarantees an optimal solution, often without the use of a computer, which is necessary only for fairly large problems. When profits instead of costs are involved, the profits can be converted to *relative costs* by subtracting every number in the table from the largest number and then proceeding as in a minimization problem.

It is worth knowing that one extension of this technique can be used to prevent undesirable assignments. For example, union rules may prohibit one person's assignment to a particular job, or a manager might wish to avoid assigning an unqualified person to a job. Whatever the reason, specific combinations can be avoided by assigning a relatively high cost to that combination. In the previous example, if we wish to avoid combination 1–A, assigning a cost of $50 to that combination will achieve the desired effect, because $50 is much greater than the other costs.

Sequencing

Although loading decisions determine the machines or work centers that will be used to process specific jobs, they do not indicate the *order* in which the jobs waiting at a given work center are to be processed. **Sequencing** is concerned with determining job processing order. Sequencing decisions determine both the order in which jobs are processed at various work centers and the order in which jobs are processed at individual **workstations** *within* the work centers.

sequencing Determining the order in which jobs at a work center will be processed.

workstation An area where one or a few workers and/or machines perform similar work.

If work centers are lightly loaded and if jobs all require the same amount of processing time, sequencing presents no particular difficulties. However, for heavily loaded work centers, especially in situations where relatively lengthy jobs are involved, the order of processing can be very important in terms of costs associated with jobs waiting for processing and in terms of idle time at the work centers. In this section, we will examine some of the ways in which jobs are sequenced.

priority rules Simple heuristics used to select the order in which jobs will be processed.

job time Time needed for setup and processing of a job.

Typically, a number of jobs will be waiting for processing. **Priority rules** are simple heuristics used to select the order in which the jobs will be processed. Some of the most common are listed in Table 15.2. The rules generally rest on the assumption that job setup cost and time are *independent* of processing sequence. In using these rules, job processing times and due dates are important pieces of information. **Job time** usually includes setup and processing times. Jobs that require similar setups can lead to reduced setup times if the sequencing rule takes this into account (the rules described here do not). Due dates may be the result of delivery times promised to customers, MRP processing, or managerial decisions. They are subject to revision and must be kept current to give meaning to sequencing choices. Also, it should be noted that due dates associated with all rules except S/O and CR are for the operation about to be performed; due dates for S/O and CR are typically final due dates for orders rather than intermediate, departmental deadlines.

The priority rules can be classified as either *local* or *global.* Local rules take into account information pertaining only to a single workstation; global rules take into account information pertaining to multiple workstations. FCFS, SPT, and EDD are local rules; CR and S/O are global rules. Rush can be either local or global. As you might imagine, global rules require more effort than local rules. A major complication in global sequencing is that not all jobs require the same processing or even the same order of processing. As a result, the set of jobs is different for different workstations. Local rules are particularly useful for bottleneck operations, but they are not limited to those situations.

A number of assumptions apply when using the priority rules; Table 15.3 lists them. In effect, the priority rules pertain to *static* sequencing: For simplicity, it is assumed that there is no variability in either setup or processing times, or in the set of jobs. The assumptions make the scheduling problem manageable. In practice, jobs may be delayed or canceled, and new jobs may arrive, requiring schedule revisions.

TABLE 15.2
Possible priority rules

FCFS (first come, first served): Jobs are processed in the order in which they arrive at a machine or work center.
SPT (shortest processing time): Jobs are processed according to processing time at a machine or work center, shortest job first.
EDD (earliest due date): Jobs are processed according to due date, earliest due date first.
CR (critical ratio): Jobs are processed according to smallest ratio of time remaining until due date to processing time remaining.
S/O (slack per operation): Jobs are processed according to average slack time (time until due date minus remaining time to process). Compute by dividing slack time by number of remaining operations, including the current one.
Rush: Emergency or preferred customers first.

TABLE 15.3
Assumptions of priority rules

The set of jobs is known; no new jobs arrive after processing begins; and no jobs are canceled.
Setup time is independent of processing sequence.
Setup time is deterministic.
Processing times are deterministic rather than variable.
There will be no interruptions in processing such as machine breakdowns, accidents, or worker illness.

The effectiveness of any given sequence is frequently judged in terms of one or more *performance measures*. The most frequently used performance measures follow:

Job flow time. This is the length of time a job is at a particular workstation or work center. It includes not only actual processing time but also any time waiting to be processed, transportation time between operations, and any waiting time related to equipment breakdowns, unavailable parts, quality problems, and so on. Job flow time is the length of time that begins when a job arrives at the shop, workstation, or work center, and ends when it leaves the shop, workstation, or work center. The average flow time for a group of jobs is equal to the total flow time for the jobs divided by the number of jobs.

Job lateness. This is the length of time the job completion date is expected to exceed the date the job was due or promised to a customer. It is the difference between the actual completion time and the due date. If we only record differences for jobs with completion times that exceed due dates, and assign zeros to jobs that are early, the term we use to refer to that is job *tardiness*.

Makespan. **Makespan** is the total time needed to complete a *group* of jobs. It is the length of time between the start of the first job in the group and the completion of the last job in the group. If processing involves only one work center, makespan will be the same regardless of the priority rule being used.

makespan Total time needed to complete a group of jobs from the beginning of the first job to the completion of the last job.

Average number of jobs. Jobs that are in a shop are considered to be work-in-process inventory. The average work-in-process for a group of jobs can be computed using the following formula:

Average number of jobs = Total flow time ÷ Makespan

If the jobs represent equal amounts of inventory, the average number of jobs will also reflect the average work-in-process inventory.

Of these rules, rush scheduling is quite simple and needs no explanation. The other rules and performance measures are illustrated in the following two examples.

EXAMPLE 2

Processing times (including setup times) and due dates for six jobs waiting to be processed at a work center are given in the following table. Determine the sequence of jobs, the average flow time, average tardiness, and average number of jobs at the work center, for each of these rules:

a. FCFS

b. SPT

c. EDD

d. CR

Job	Processing Time (days)	Due Date (days)
A	2	7
B	8	16
C	4	4
D	10	17
E	5	15
F	12	18

Assume jobs arrived in the order shown.

SOLUTION

a. The FCFS sequence is simply A-B-C-D-E-F. The measures of effectiveness are (see table):

(1) *Average flow time:* 120/6 = 20 days.

(2) *Average tardiness:* 54/6 = 9 days.

(3) The *makespan* is 41 days. *Average number of jobs at the work center:* 120/41 = 2.93.

Job Sequence	(1) Processing Time	(2) Flow Time	(3) Due Date	(2) − (3) Days Tardy [0 if negative]
A	2	2	7	0
B	8	10	16	0
C	4	14	4	10
D	10	24	17	7
E	5	29	15	14
F	12	41	18	23
	41	120		54

The flow time column indicates *cumulative* processing time, so summing these times and dividing by the total number of jobs processed indicates the average time each job spends at the work center. Similarly, find the average number of jobs at the center by summing the flow times and dividing by the total processing time.

b. Using the SPT rule, the job sequence is A-C-E-B-D-F (see the following table). The resulting values for the three measures of effectiveness are

(1) *Average flow time:* 108/6 = 18 days.

(2) *Average tardiness:* 40/6 = 6.67 days.

(3) *Average number of jobs at the work center:* 108/41 = 2.63.

Job Sequence	(1) Processing Time	(2) Flow Time	(3) Due Date	(2) − (3) Days Tardy [0 if negative]
A	2	2	7	0
C	4	6	4	2
E	5	11	15	0
B	8	19	16	3
D	10	29	17	12
F	12	41	18	23
	41	108		40

c. Using earliest due date as the selection criterion, the job sequence is C-A-E-B-D-F. The measures of effectiveness are (see table):

(1) *Average flow time:* 110/6 = 18.33 days.

(2) *Average tardiness:* 38/6 = 6.33 days.

(3) *Average number of jobs at the work center:* 110/41 = 2.68.

Job Sequence	(1) Processing Time	(2) Flow Time	(3) Due Date	(2) − (3) Days Tardy [0 if negative]
C	4	4	4	0
A	2	6	7	0
E	5	11	15	0
B	8	19	16	3
D	10	29	17	12
F	12	41	18	23
	41	110		38

d. Using the critical ratio we find

Job Sequence	Processing Time	Due Date	Critical Ratio Calculation
A	2	7	(7 − 0)/ 2 = 3.5
B	8	16	(16 − 0)/ 8 = 2.0
C	4	4	(4 − 0)/ 4 = 1.0 (lowest)
D	10	17	(17 − 0)/10 = 1.7
E	5	15	(15 − 0)/ 5 = 3.0
F	12	18	(18 − 0)/12 = 1.5

At day 4 [C completed], the critical ratios are

Job Sequence	Processing Time	Due Date	Critical Ratio Calculation
A	2	7	(7 − 4)/ 2 = 1.5
B	8	16	(16 − 4)/ 8 = 1.5
C	—	—	—
D	10	17	(17 − 4)/10 = 1.3
E	5	15	(15 − 4)/ 5 = 2.2
F	12	18	(18 − 4)/12 = 1.17 (lowest)

At day 16 [C and F completed], the critical ratios are

Job Sequence	Processing Time	Due Date	Critical Ratio Calculation
A	2	7	(7 − 16)/ 2 = −4.5 (lowest)
B	8	16	(16 − 16)/ 8 = 0.0
C	—	—	—
D	10	17	(17 − 16)/10 = 0.1
E	5	15	(15 − 16)/ 5 = −0.2
F	—	—	—

At day 18 [C, F, and A completed], the critical ratios are

Job Sequence	Processing Time	Due Date	Critical Ratio Calculation
A	—	—	—
B	8	16	(16 − 18)/ 8 = −0.25
C	—	—	—
D	10	17	(17 − 18)/10 = −0.10
E	5	15	(15 − 18)/ 5 = −0.60 (lowest)
F	—	—	—

At day 23 [C, F, A, and E completed], the critical ratios are

Job Sequence	Processing Time	Due Date	Critical Ratio Calculation
A	—	—	—
B	8	16	(16 − 23)/ 8 = −0.875 (lowest)
C	—	—	—
D	10	17	(17 − 23)/10 = −0.60
E	—	—	—
F	—	—	—

The job sequence is C-F-A-E-B-D, and the resulting values for the measures of effectiveness are

(1) *Average flow time:* 133/6 = 22.17 days.

(2) *Average tardiness:* 58/6 = 9.67 days.

(3) *Average number of jobs at the work center:* 133/41 = 3.24.

Sequence	(1) Processing Time	(2) Flow Time	(3) Due Date	(2) − (3) Days Tardy
C	4	4	4	0
F	12	16	18	0
A	2	18	7	11
E	5	23	15	8
B	8	31	16	15
D	10	41	17	24
	41	133		58

The results of these four rules are summarized in Table 15.4.

TABLE 15.4
Comparison of the four rules for Example 2

Rule	Average Flow Time (days)	Average Tardiness (days)	Average Number of Jobs at the Work Center
FCFS	20.00	9.00	2.93
SPT	18.00	6.67	2.63
EDD	18.33	6.33	2.68
CR	22.17	9.67	3.24

In this example, the SPT rule was the best according to two of the measures of effectiveness and a little worse than the EDD rule on average tardiness. The CR rule was the worst in every case. For a different set of numbers, the EDD rule (or perhaps another rule not mentioned here) might prove superior to SPT in terms of average job tardiness or some other measure of effectiveness. However, SPT is always superior in terms of minimizing flow time and, hence, in terms of minimizing the average number of jobs at the work center and completion time.

Generally speaking, the FCFS rule and the CR rule turn out to be the least effective of the rules.

The primary limitation of the FCFS rule is that long jobs will tend to delay other jobs. If a process consists of work on a number of machines, machine idle time for downstream workstations will increase. However, for service systems in which customers are directly involved, the FCFS rule is by far the dominant priority rule, mainly because of the inherent fairness but also because of the inability to obtain realistic estimates of processing time for individual jobs. The FCFS rule also has the advantage of simplicity. If other measures are important when there is high customer contact, companies may adopt the strategy of moving processing to the "backroom" so they don't necessarily have to follow FCFS.

Because the SPT rule always results in the lowest (i.e., optimal) average completion (flow) time, it can result in lower in-process inventories. And because it often provides the lowest (optimal) average tardiness, it can result in better customer service levels. Finally, since it always involves a lower average number of jobs at the work center, there tends to be less congestion in the work area. SPT also minimizes downstream idle time. However, due dates are often uppermost in managers' minds, so they may not use SPT because it doesn't incorporate due dates.

The major disadvantage of the SPT rule is that it tends to make long jobs wait, perhaps for rather long times (especially if new, shorter jobs are continually added to the system). Various modifications may be used in an effort to avoid this. For example, after waiting for a given time period, any remaining jobs are automatically moved to the head of the line. This is known as the *truncated* SPT rule.

The EDD rule directly addresses due dates and usually minimizes lateness. Although it has intuitive appeal, its main limitation is that it does not take processing time into account. One possible consequence is that it can result in some jobs waiting a long time, which adds to both in-process inventories and shop congestion.

The CR rule is easy to use and has intuitive appeal. Although it had the poorest showing in Example 2 for all three measures, it usually does quite well in terms of minimizing job tardiness. Therefore, if job tardiness is important, the CR rule might be the best choice among the rules.

Let's take a look now at the S/O (slack per operation) rule.

EXAMPLE 3

Use the S/O rule to schedule the following jobs. Note that processing time includes the time remaining for the current and subsequent operations. In addition, you will need to know the number of operations remaining, including the current one.

Job	Remaining Processing Time	Due Date	Remaining Number of Operations
A	4	14	3
B	16	32	6
C	8	8	5
D	20	34	2
E	10	30	4
F	18	30	2

SOLUTION

Determine the difference between the due date and the processing time for each operation. Divide the difference by the number of remaining operations, and rank them from low to high. This yields the sequence of jobs:

Job	(1) Remaining Processing Time	(2) Due Date	(3) (2) − (1) Slack	(4) Remaining Number of Operations	(5) (3) ÷ (4) Ratio	(6) Rank
A	4	14	10	3	3.33	3
B	16	32	16	6	2.67	2
C	8	8	0	5	0	1
D	20	34	14	2	7.00	6
E	10	30	20	4	5.00	4
F	18	30	12	2	6.00	5

The indicated sequence (see column 6) is C-B-A-E-F-D.

Using the S/O rule, the designated job sequence may change after any given operation, so it is important to reevaluate the sequence after each operation. Note that any of the previously mentioned priority rules could be used on a station-by-station basis for this situation; the only difference is that the S/O approach incorporates downstream information in arriving at a job sequence.

In reality, many priority rules are available to sequence jobs, and some other rule might provide superior results for a given set of circumstances. The purpose in examining these few rules is to provide insight into the nature of sequencing rules. Each shop or organization should consider carefully its own circumstances and the measures of effectiveness it feels are important, when selecting a rule to use.

The following section describes a special-purpose algorithm that can be used to sequence a set of jobs that must all be processed at the same two machines or work centers.

Johnson's rule Technique for minimizing makespan for a group of jobs to be processed on two machines or at two work centers.

Sequencing Jobs through Two Work Centers[1]

Johnson's rule is a technique that managers can use to minimize the makespan for a group of jobs to be processed on two machines or at two successive work centers (sometimes referred

[1]For a description of a heuristic that can be used for the case where a set of jobs is to be processed through more than two work centers, see Thomas Vollmann et al., *Manufacturing Planning and Control Systems,* 4th ed. (New York: Irwin/McGraw-Hill, 1997), p. 532.

to as a two-machine flow shop).[2] It also minimizes the total idle time at the work centers. For the technique to work, several conditions must be satisfied:

1. Job time (including setup and processing) must be known and constant for each job at each work center.
2. Job times must be independent of the job sequence.
3. All jobs must follow the same two-step work sequence.
4. Job priorities cannot be used.
5. All units in a job must be completed at the first work center before the job moves on to the second work center.

Determination of the optimum sequence involves these steps:

1. List the jobs and their times at each work center.
2. Select the job with the shortest time. If the shortest time is at the first work center, schedule that job first; if the time is at the second work center, schedule the job last. Break ties arbitrarily.
3. Eliminate the job and its time from further consideration.
4. Repeat steps 2 and 3, working toward the center of the sequence, until all jobs have been scheduled.

When significant idle time at the second work center occurs, job splitting at the first center just prior to the occurrence of idle time may alleviate some of it and also shorten throughput time. In Example 4, this was not a concern. The last solved problem at the end of this chapter illustrates the use of job splitting.

EXAMPLE 4

A group of six jobs is to be processed through a two-machine flow shop. The first operation involves cleaning and the second involves painting. Determine a sequence that will minimize the total completion time for this group of jobs. Processing times are as follows:

	PROCESSING TIME (HOURS)	
Job	**Work Center 1**	**Work Center 2**
A	5	5
B	4	3
C	8	9
D	2	7
E	6	8
F	12	15

SOLUTION

a. Select the job with the shortest processing time. It is job D, with a time of two hours.

b. Since the time is at the first center, schedule job D first. Eliminate job D from further consideration.

c. Job B has the next shortest time. Since it is at the second work center, schedule it last and eliminate job B from further consideration. We now have

1st	2nd	3rd	4th	5th	6th
D					B

[2]S. M. Johnson, "Optimal Two- and Three-Stage Production with Setup Times Included," *Naval Research Quarterly* 1 (March 1954), pp. 61–68.

d. The remaining jobs and their times are

Job	1	2
A	5	5
C	8	9
E	6	8
F	12	15

Note that there is a tie for the shortest remaining time: job A has the same time at each work center. It makes no difference, then, whether we place it toward the beginning or the end of the sequence. Suppose it is placed arbitrarily toward the end. We now have

1st	2nd	3rd	4th	5th	6th
D				A	B

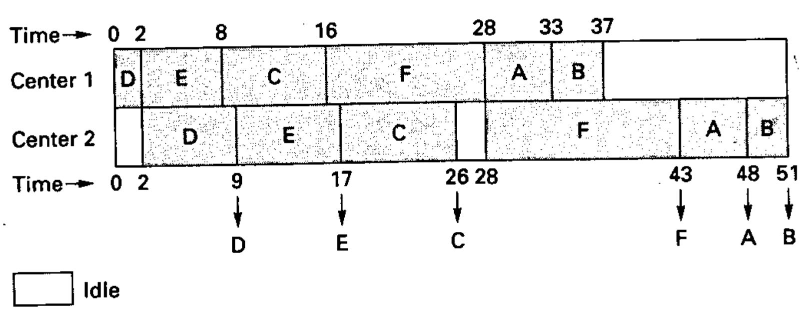
e. The shortest remaining time is six hours for job E at work center 1. Thus, schedule that job toward the beginning of the sequence (after job D). Thus,

1st	2nd	3rd	4th	5th	6th
D	E			A	B

f. Job C has the shortest time of the remaining two jobs. Since it is for the first work center, place it third in the sequence. Finally, assign the remaining job (F) to the fourth position and the result is

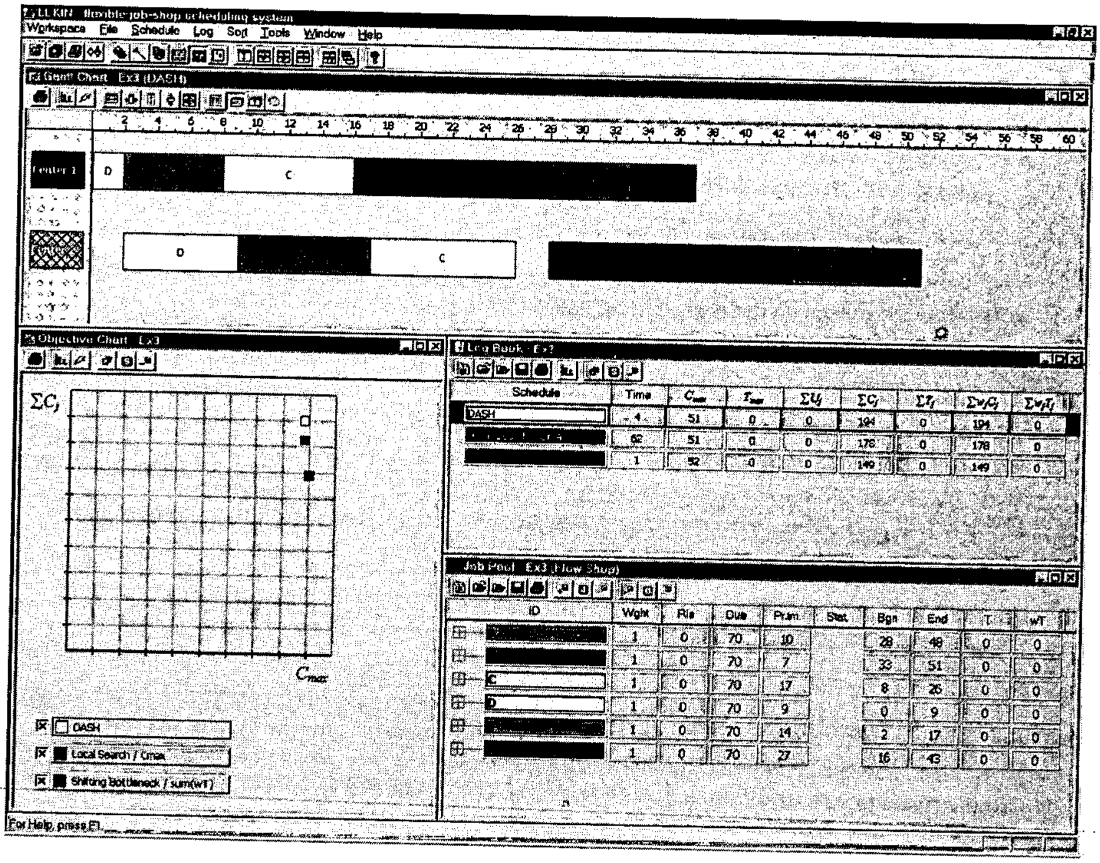
1st	2nd	3rd	4th	5th	6th
D	E	C	F	A	B

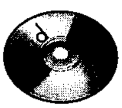
g. One way to determine the throughput time and idle times at the work centers is to construct a chart:



Thus, the group of jobs will take 51 hours to complete. The second work center will wait two hours for its first job and also wait two hours after finishing job C. Center 1 will be finished in 37 hours. Of course, idle periods at the beginning or end of the sequence could be used to do other jobs or for maintenance or setup/teardown activities.

Using the Lekin software on your CD would produce this output:




Scheduling Program

Sequencing Jobs When Setup Times Are Sequence-Dependent

The preceding discussion and examples assumed that machine setup times are independent of processing order, but in many instances that assumption is not true. Consequently, a manager may want to schedule jobs at a workstation taking those dependencies into account. The goal is to minimize total setup time.

Consider the following table, which shows workstation machine setup times based on job processing order. For example, if job A is followed by job B, the setup time for B will be 6 hours. Furthermore, if job A is completed first, followed by job B, job C will then follow job B and have a setup time of 4 hours. If a job is done first, its setup time will be the amount shown in the setup time column to the right of the job. Thus, if job A is done first, its setup time will be 3 hours.

			Resulting following job setup time (hrs.) is		
		Setup time (hrs.)	**A**	**B**	**C**
If the preceding job is	**A**	**3**	—	6	2
	B	**2**	1	—	4
	C	**2**	5	3	—

The simplest way to determine which sequence will result in the lowest total setup time is to list each possible sequence and determine its total setup time. In general, the number of different alternatives is equal to $n!$, where n is the number of jobs. Here, n is 3, so $n! = 3 \times 2 \times 1 = 6$. The six alternatives and their total setup times are

Sequence	Setup Times	Total
A-B-C	3 + 6 + 4 =	13
A-C-B	3 + 2 + 3 =	8
B-A-C	2 + 1 + 2 =	5 (best)
B-C-A	2 + 4 + 5 =	11
C-A-B	2 + 5 + 6 =	13
C-B-A	2 + 3 + 1 =	6

Hence, to minimize total setup time, the manager would select sequence B-A-C.

This procedure is relatively simple to do manually when the number of jobs is two or three. However, as the number of jobs increases, the list of alternatives quickly becomes larger. For example, six jobs would have 720 alternatives. In such instances, a manager would employ a computer to generate the list and identify the best alternative(s). (Note that more than one alternative may be tied for the lowest setup time.)

Why Scheduling Can Be Difficult

Scheduling can be difficult for a number of reasons. One is that in reality, an operation must deal with variability in setup times, processing times, interruptions, and changes in the set of jobs. Another major reason is that except for small job sets, there is no method for identifying the optimal schedule, and it would be virtually impossible to sort through the vast number of possible alternatives to obtain the best schedule. As a result, scheduling is far from an exact science and, in many instances, is an ongoing task for a manager.

Computer technology reduces the burden of scheduling and makes real-time scheduling possible.

Minimizing Scheduling Difficulties

There are a number of actions that managers can consider to minimize scheduling problems, such as

- Setting realistic due dates.
- Focusing on bottleneck operations: First, try to increase the capacity of the operations. If that is not possible or feasible, schedule the bottleneck operations first, and then schedule the nonbottleneck operations around the bottleneck operations.
- Considering lot splitting for large jobs. This probably works best when there are relatively large differences in job times.

The Theory of Constraints

Another approach to scheduling was developed and promoted by Eli Goldratt.[3] He avoided much of the complexity often associated with scheduling problems by simply focusing on *bottleneck* operations (i.e., those for which there was insufficient capacity—in effect, a work center with zero idle time). He reasoned the output of the system was limited by the output of the bottleneck operation(s); therefore, it was essential to schedule the nonbottleneck operations in a way that minimized the idle time of the bottleneck operation(s). Thus, idle time of nonbottleneck operations was not a factor in overall productivity of the system, as long as the bottleneck operations were used effectively. The result was a technique for scheduling intermittent production systems that was simpler and less time-consuming to use.

The technique uses a *drum-buffer-rope* conceptualization to manage the system. The "drum" is the schedule; it sets the pace of production. The goal is to schedule to make maximum use of bottleneck resources. The "buffer" refers to potentially constraining resources outside of the

[3]Eli Goldratt, *The General Theory of Constraints* (New Haven, CT: Avraham Y. Institute, 1989).

bottleneck. The role of the buffer is to keep a small amount of inventory ahead of the bottleneck operation to minimize the risk of having it be idle. The "rope" represents the synchronizing of the sequence of operations to ensure effective use of the bottleneck operations. The goal is to avoid costly and time-consuming multiple setups, particularly of capacity-constrained resources, so they do not become bottlenecks too.

Goldratt also developed a system of varying batch sizes to achieve the greatest output of bottleneck operations. He used the term *process batch* to denote the basic lot size for a job and the term *transfer batch* to denote a portion of the basic lot that could be used during production to facilitate utilization of bottleneck operations. In effect, a lot could be split into two or more parts. Splitting a large lot at one or more operations preceding a bottleneck operation would reduce the waiting time of the bottleneck operation.

ADDITIONAL SERVICE CONSIDERATIONS

Scheduling service systems presents certain problems not generally encountered in manufacturing systems. This is due primarily to (1) the inability to store or inventory services and (2) the random nature of customer requests for service. In some situations, the second difficulty can be moderated by using appointment or reservation systems, but the inability to store services in most cases is a fact of life that managers must contend with.

An important goal in service systems is to match the flow of customers and service capabilities. An ideal situation is one that has a smooth flow of customers through the system. This would occur if each new customer arrives at the precise instant that the preceding customer's service is completed, as in a physician's office, or in air travel if the demand just equals the number of available seats. In each of these situations customer waiting time would be minimized, and the service system staff and equipment would be fully utilized. Unfortunately, the random nature of customer requests for service that generally prevails in service systems makes it nearly impossible to provide service capability that matches demand. Moreover, if service times are subject to variability—say, because of differing processing requirements—the inefficiency of the system is compounded. The inefficiencies can be reduced if arrivals can be scheduled (e.g., appointments), as in the case of doctors and dentists. However, in many situations appointments are not possible (supermarkets, gas stations, theaters, hospital emergency rooms, repair of equipment breakdowns). Chapter 18, on waiting lines, focuses on those kinds of situations. There, the emphasis is on intermediate-term decisions related to service capacity. In this section, we will concern ourselves with short-term *scheduling,* in which much of the capacity of a system is essentially fixed, and the goal is to achieve a certain degree of customer service by efficient utilization of that capacity.

Customers waiting to be served. In many situations, appointments are not possible, and waiting lines are inevitable.

Scheduling in service systems may involve scheduling (1) customers, (2) the workforce, and (3) equipment. Scheduling customers often takes the form of appointment systems or reservation systems.

Appointment Systems

Appointment systems are intended to control the timing of customer arrivals in order to minimize customer waiting while achieving a high degree of capacity utilization. A doctor can use an appointment system to schedule patients' office visits during the afternoon, leaving the mornings free for hospital duties. Similarly, an attorney can schedule client meetings around court appearances. Even with appointments, however, problems can still arise due to lack of punctuality on the part of patients or clients, no-shows, and the inability to completely control the length of contact time (e.g., a dentist might run into complications in filling a tooth and have to spend additional time with a patient, thus backing up later appointments). Some of this can be avoided by trying to match the time reserved for a patient or client with the specific needs of that case rather than setting appointments at regular intervals. Even with the problems of late arrivals and no-shows, the appointment system is a tremendous improvement over random arrivals.

Reservation Systems

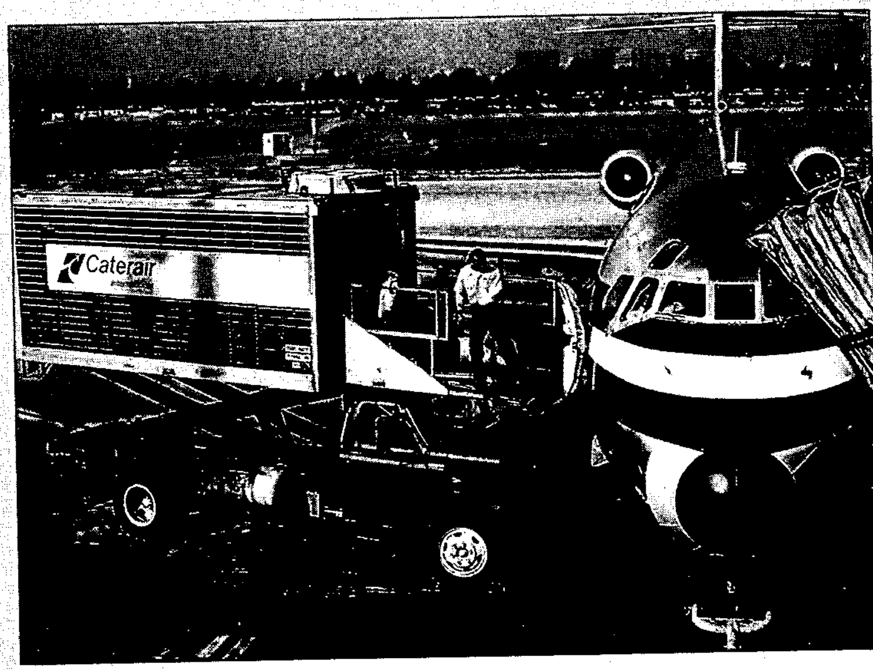
Reservation systems are designed to enable service systems to formulate a fairly accurate estimate of the demand on the system for a given time period and to minimize customer disappointment generated by excessive waiting or inability to obtain service. Reservation systems are widely used by resorts, hotels and motels, restaurants, and some modes of transportation (e.g., airlines, car rentals). In the case of restaurants, reservations enable management to spread out or group customers so that demand matches service capabilities. Late arrivals and no-shows can disrupt the system. One approach to the no-show problem is to use decision theory (described in the supplement to Chapter 5). The problem also can be viewed as a single-period inventory problem, as described in Chapter 11.

Servicing Passenger Planes

READING

Robert L. Crandall

www.americanair.com



A meal supply truck arrives to load supplies onto an American Airlines plane before its scheduled departure.

Before takeoff and after landing, you've probably noticed lots of people and various types of vehicles and equipment busily moving around on the ground outside with no apparent game plan, particularly at larger airports. Actually, all that activity is carefully orchestrated, and because the people involved are an important part of our team, I'd like to tell you what the hustle and bustle is all about.

When a flight lands and approaches the terminal, ramp personnel guide the aircraft to its parking position and after it comes to a stop, put chocks under its wheels. As soon as that's been done, other workers hook up ground-based power and air conditioning. Electric power comes from what looks like a large, industrial-strength extension cord plugged into the lower portion of the nose section. Heated or cooled air goes into the cabin via the big yellow hoses that run from the airplane either to the terminal, in cities where we have central air-handling facilities or, in others, to mobile air-handling units.

On the airplane, meanwhile, flight attendants open the door and as passengers begin deplaning, a mechanic squeezes past them to get a debriefing from the cockpit and check to see if any maintenance work must be done.

Once all deplaning passengers are off, the cabin cleaners go into high gear on most flights, cleaning our seatback pockets, tidying up the cabin, cleaning the lavatories, doing a light vacuuming, repositioning safety belts for each seat's next occupant, and so forth. (A more thorough cleaning is done each night.)

Simultaneously, out on the ramp, our people are unloading baggage, freight, and mail from the airplane's belly compartments and beginning the process of sorting by various categories and destinations. In addition to the bags and cargo that have reached their destination, which must be delivered promptly to passengers and shippers, some must be transferred to other American or American Eagle flights, and still others must be transferred to other carriers. Complicating matters further, baggage, freight, and mail are often handled in different facilities on the airport property.

If a meal has been served or is planned for the outbound flight, catering trucks pull up to service the First Class and main cabin galleys. Another special truck services the lavatory holding tanks, and in the midst of all this, mechanics are dealing

(continued)

(concluded)

with any problems reported by the crew and doing their own walk-around inspections.

Once all that is complete, customers start to board the aircraft for its next flight and everything happens in reverse. Ground workers start loading baggage in the forward belly and freight and mail in the rear. Fuel trucks pull up to refuel most flights. The airplanes must be "watered" as well; fresh water is pumped aboard from either a water truck or servicing equipment built into the gate itself. During cold-weather months, de-icing trucks add another element of ramp activity as they spray fluid on the airplane's wings and fuselage.

Most of the work on the ramp is done by our own people, principally fleet-service personnel, but there are also various services, like catering, which are performed by contractors.

All this simultaneous activity can create conflicts. Baggage carts unloading the forward hold can encroach on the ground space needed by the trucks catering the First Class cabin, for example, and fuelers perform their function in the space needed by those unloading freight and mail. The ramp crew chiefs are the conductors, orchestrating the entire production, overseeing the detail, and seeing to it that all gets done without mishap—and on time.

It's a delicate balancing act, and although our customers rarely come in contact with the folks working on the ramp, they are an important part of a team that aims to serve every customer well and keep our operation running safely and on time.

Source: Servicing Passenger Plans, Robert L. Crandall, *American Way*, March 15, 1995.

Scheduling the Workforce

Scheduling customers is demand management. Scheduling the workforce is capacity management. This approach works best when demand can be predicted with reasonable accuracy. This is often true for restaurants, theaters, rush-hour traffic, and similar instances that have repeating patterns of intensity of customer arrivals. Scheduling hospital personnel, police, and telephone operators for catalog sales, credit card companies, and mutual fund companies also comes under this heading. An additional consideration is the extent to which variations in customer demands can be met with workforce flexibility. Thus, capacity can be adjusted by having cross-trained workers who can be temporarily assigned to help out on bottleneck operations during periods of peak demand.

Various constraints can affect workforce scheduling flexibility, including legal, behavioral, technical—such as workers' qualifications to perform certain operations—and budget constraints. Union contracts may provide still more constraints.

Cyclical Scheduling

In many services (e.g., hospitals, police departments, fire departments, restaurants, and supermarkets) the scheduling requirements are fairly similar: Employees must be assigned to work shifts or time slots, and have days off, on a repeating or cyclical basis. Here is a method for determining both a schedule and the minimum number of workers needed.

Generally a basic work pattern is set (e.g., work five consecutive days, have two consecutive days off), and a list of staffing needs for the schedule cycle (usually one week) is given. For example:

Day	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Staff needed	2	4	3	4	6	5	5

A fairly simple but effective approach for determining the minimum number of workers needed is the following: Begin by repeating the staff needs for Worker 1. Then,

1. Make the first worker's assignment such that the two days with the lowest need (i.e., lowest sum) are designated as days off. Here Monday–Tuesday has the two lowest consecutive requirements. Circle those days. (Note, in some instances, Sun–Mon might yield the two lowest days.) In case of a tie, pick the pair with the lowest adjacent requirement. If there is still a tie, pick arbitrarily.

Day	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Staff needed	2	4	3	4	6	5	5
Worker 1	(2	4)	3	4	6	5	5

2. Subtract one from each day's requirement, except for the circled days. Assign the next employee, again using the two lowest consecutive days as days off. Circle those days.

Day	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Staff needed	2	4	3	4	6	5	5
Worker 1	(2	4)	3	4	6	5	5
Worker 2	2	4	(2	3)	5	4	4

3. Repeat the preceding step for each additional worker until all staffing requirements have been met. However, don't subtract from a value of zero.

Day	Mon	Tue	Wed	Thu	Fri	Sat	Sun	
Staff needed	2	4	3	4	6	5	5	
Worker 1	(2	4)	3	4	6	5	5	
Worker 2	2	4	(2	3)	5	4	4	
Worker 3	(1	3)	2	3	4	3	3	
Worker 4	1)	3	1	2	3	2	(2	(tie)
Worker 5	1	2	(0	1)	2	1	2	
Worker 6	0	(1	0)	1	1	0	1	(multiple ties)
Worker 7	0	1	0	0	0	0	0	(tie)
No. working:	2	4	3	4	6	5	5	

To identify the days each worker is working, go across each worker's row to find the non-zero values that are not circled, signifying that the worker is assigned for those days. Similarly, to find the workers who are assigned to work for any particular day, go down that day's column to find the non-zero values that are not circled. Note: Worker 6 will only work four days, and worker 7 will only work *one* day.

Scheduling Multiple Resources

In some situations, it is necessary to coordinate the use of more than one resource. For example, hospitals must schedule surgeons, operating room staffs, recovery room staffs, admissions, special equipment, nursing staffs, and so on. Educational institutions must schedule faculty, classrooms, audiovisual equipment, and students. As you might guess, the greater the number of resources to be scheduled simultaneously, the greater the complexity and the less likely that an optimum schedule can be achieved. The problem is further complicated by the variable nature of such systems. For example, educational institutions frequently change their course offerings, student enrollments change, and students exhibit different course-selection patterns.

Some schools and hospitals are using computer software to assist them in devising acceptable schedules, although many appear to be using intuitive approaches with varying degrees of success.

Airlines are another example of service systems that require the scheduling of multiple resources. Flight crews, aircraft, baggage handling equipment, ticket counters, gate personnel, boarding ramps, and maintenance personnel all have to be coordinated. Furthermore, government regulations on the number of hours a pilot can spend flying place an additional restriction on the system. Another interesting variable is that, unlike most systems, the flight crews and the equipment do not remain in one location. Moreover, the crew and the equipment are not usually scheduled as a single unit. Flight crews are often scheduled so that they return to their base city every two days or more often, and rest breaks must be considered. On the other hand, the aircraft may be in almost continuous use except for periodic maintenance and repairs. Consequently, flight crews commonly follow different trip patterns than that of the aircraft.

There are also other activities that must be scheduled, some of which are described by American Airlines Chairman Robert L. Crandall in the reading on page 677.

Service systems are prone to slowdowns when variability in demand for services causes bottlenecks. Part of the difficulty lies in predicting which operations will become bottlenecks. Moreover, bottlenecks may shift with the passage of time, so that different operations become bottleneck operations—further complicating the problem.

Operations Strategy

Scheduling can either help or hinder operations strategy. If scheduling is done well, products or services can be made or delivered in a timely manner. Resources can be used to best advantage and customers will be satisfied. Scheduling not performed well will result in inefficient use of resources and possibly dissatisfied customers.

The implication is clear: Management should not overlook the important role that scheduling plays in the success of an organization and the supply chain, giving a competitive advantage if done well or disadvantage if done poorly. Time-based competition depends on good scheduling. Coordination of materials, equipment use, and employee time is an important function of operations management. It is not enough to have good design, superior quality, and the other elements of a well-run organization if scheduling is done poorly—just as it is not enough to own a well-designed and well-made car, with all the latest features for comfort and safety, if the owner doesn't know how to drive it!

SUMMARY

Scheduling involves the timing and coordination of operations. Such activities are fundamental to virtually every organization. Scheduling problems differ according to whether a system is designed for high volume, intermediate volume, or low volume. Scheduling problems are particularly complex for job shops (low volume) because of the variety of jobs these systems are required to process.

The two major problems in job-shop scheduling are assigning jobs to machines or work centers, and designating the sequence of job processing at a given machine or work center. Gantt load charts are frequently employed to help managers visualize workloads, and they are useful for describing and analyzing sequencing alternatives. In addition, both heuristic and optimizing methods are used to develop loading and sequencing plans. For the most part, the optimization techniques can be used only if certain assumptions can be made.

Customer requirements in service systems generally present very different circumstances than those encountered in manufacturing systems. Some services can use appointments and reservations for scheduling purposes, although not all systems are amenable to this. When multiple resources are involved, the task of balancing the system can be fairly complex.

KEY TERMS

SOLVED PROBLEMS

Problem 1

The assignment method. The following table contains information on the cost to run three jobs on four available machines. Determine an assignment plan that will minimize costs.

		MACHINE			
		A	**B**	**C**	**D**
	1	12	16	14	10
Job	**2**	9	8	13	7
	3	15	12	9	11

Solution

In order for us to be able to use the assignment method, the numbers of jobs and machines must be equal. To remedy this situation, add a *dummy* job with costs of 0, and then solve as usual.

		MACHINE			
		A	B	C	D
	1	12	16	14	10
	2	9	8	13	7
Job	3	15	12	9	11
(dummy)	4	0	0	0	0

a. Subtract the smallest number from each row. The results are

		MACHINE			
		A	B	C	D
	1	2	6	4	0
	2	2	1	6	0
Job	3	6	3	0	2
	4	0	0	0	0

b. Subtract the smallest number in each column. (Because of the dummy zeros in each column, the resulting table will be unchanged.)

c. Determine the minimum number of lines needed to cross out the zeros. One possible way is

		Machine			
		A	*B*	*C*	*D*
	1	2	6	4	0
	2	2	1	6	0
Job	3	6	3	0	2
	4	0	0	0	0

d. Because the number of lines is less than the number of rows, modify the numbers.

(1) Subtract the smallest uncovered number (1) from each uncovered number.

(2) Add the smallest uncovered number to numbers at line intersections.

The result is

		MACHINE			
		A	B	C	D
	1	1	5	4	0
	2	1	0	6	0
Job	3	5	2	0	2
	4	0	0	1	1

e. Test for optimality:

		Machine			
		A	*B*	*C*	*D*
	1	1	5	4	0
	2	1	0	6	0
Job	3	5	2	0	2
	4	0	0	1	1

Because the minimum number of lines equals the number of rows, an optimum assignment can be made.

f. Assign jobs to machines. Start with rows 1 and 3, since they each have one zero, and columns A and C, also with one zero each. After each assignment, cross out all the numbers in that row *and* column. The result is

		Machine			
		A	B	C	D
	1	1	5	4	[0]
	2	1	[0]	6	0
Job	3	5	2	[0]	2
	4	[0]	0	1	1

Notice that there is only one assignment in each row, and only one assignment in each column.

g. Compute total costs, referring to the original table:

1-D	$10
2-B	8
3-C	9
4-A	0
	$27

h. The implication of assignment 4-A is that machine A will not be assigned a job. It may remain idle or be used for another job.

Problem 2

Priority rules. Job times (including processing and setup) are shown in the following table for five jobs waiting to be processed at a work center:

Job	Job Time (hours)	Due Date (hours)
a	12	15
b	6	24
c	14	20
d	3	8
e	7	6

Determine the processing sequence that would result from each of these priority rules:

a. SPT

b. EDD

Solution

Assume job times are independent of processing sequence.

	a. SPT		b. EDD	
Job	Job Time	Processing Order	Hour Due	Processing CR
a	12	4	15	3
b	6	2	24	5
c	14	5	20	4
d	3	1	8	2
e	7	3	6	1

Problem 3

Priority rules. Using the job times and due dates from Solved Problem 2, determine each of the following performance measures for first-come, first-served processing order:

a. Makespan

b. Average flow time

c. Average tardiness
d. Average number of jobs at the workstation.

Solution

Job	Job Time	Flow Time	Hour Due	Hours Tardy
a	12	12	15	0
b	6	18	24	0
c	14	32	20	12
d	3	35	8	27
e	7	42	6	36
Total		139		75

a. Makespan = 42 hours

b. Average flow time $= \dfrac{\text{Total flow time}}{\text{Number of jobs}} = \dfrac{139}{5} = 27.80$ hours

c. Average tardiness $= \dfrac{\text{Total hours tardy}}{\text{Number of jobs}} = \dfrac{75}{5} = 15$ hours

d. Average number of jobs at workstation $= \dfrac{\text{Total flow time}}{\text{Makespan}} = \dfrac{139}{42} = 3.31$

Problem 4

S/O rule. Using the following information, determine an order processing sequence using the S/O priority rule.

Order	Processing Time Remaining (days)	Due Date (days)	Number of Operations Remaining
A	20	30	2
B	11	18	5
C	10	6	2
D	16	23	4

Solution

Assume times are independent of processing sequence.

Order	(1) Remaining Processing Time	(2) Due Date	(3) (2) − (1) Slack	(4) Number of Operations	(5) Ratio	(6) Rank (sequence)
A	20	30	10	2	5.00	4
B	11	18	7	5	1.40	2
C	10	6	−4	2	−2.00	1
D	16	23	7	4	1.75	3

(Note that one ratio is negative. When negatives occur, assign the *lowest* rank to the *most negative* number.)

Problem 5

Sequencing jobs through two work centers. Use Johnson's rule to obtain the optimum sequence for processing the jobs shown through work centers A and B.

	JOB TIMES (HOURS)	
Job	Work Center A	Work Center B
a	2.50	4.20
b	3.80	1.50
c	2.20	3.00
d	5.80	4.00
e	4.50	2.00

Solution

a. Identify the smallest time: job b (1.50 hours at work center B). Because the time is for B, schedule this job last.

b. The next smallest time is job e (2.00 hours at B). Schedule job e next to last.

c. Identify the smallest remaining job time: job c (2.20 hours at center A). Since the time is in the A column, schedule job c first. At this point, we have:

c, ______, ______, e, b

d. The smallest time for the remaining jobs is 2.50 hours for job a at center A. Schedule this job after job c. The one remaining job (job d) fills the remaining slot. Thus, we have

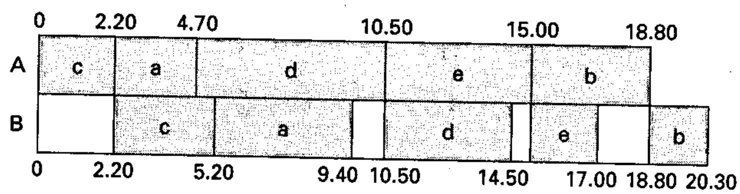
c-a-d-e-b

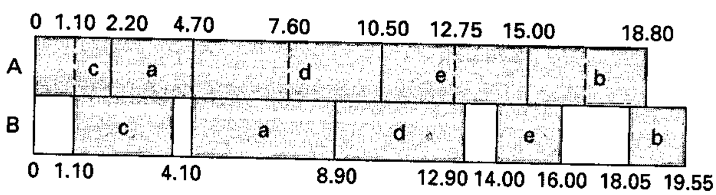
Problem 6

For Solved Problem 5, determine what effect splitting jobs c, d, e, and b in work center A would have on the idle time of work center B and on the throughput time. Assume that each job can be split into two equal parts.

Solution

We assume that the processing sequence remains unchanged and proceed on that basis. The solution from the previous problem is shown in the following chart. The next chart shows reduced idle time at center B when splitting is used.





An inspection of these two figures reveals that throughput time has decreased from 20.30 hours to 19.55 hours. In addition, the original idle time was 5.6 hours. After splitting certain jobs, it was reduced to 4.85 hours, so some improvement was achieved. Note that processing times at B are generally less than at A for jobs toward the end of the sequence. As a result, jobs such as e and b at B were scheduled so that they were *centered* around the finishing times of e and b, respectively, at A, to avoid having to break the jobs due to waiting for the remainder of the split job from A. Thus, the greatest advantage from job splitting generally comes from splitting earlier jobs when Johnson's rule is used for sequencing.

DISCUSSION AND REVIEW QUESTIONS

1. Why is scheduling fairly simple for repetitive systems but fairly complex for job shops?
2. What are the main decision areas of job-shop scheduling?
3. What are Gantt charts? How are they used in scheduling? What are the advantages of using Gantt charts?
4. What are the basic assumptions of the assignment method of linear programming?
5. Briefly describe each of these priority rules:
   a. FCFS *b.* SPT *c.* EDD *d.* S/O *e.* Rush
6. Why are priority rules needed?
7. What problems not generally found in manufacturing systems do service systems present in terms of scheduling the use of resources?
8. Doctors' and dentists' offices frequently schedule patient visits at regularly spaced intervals. What problems can this create? Can you suggest an alternative approach to reduce these problems? Under

what circumstances would regularly spaced appointments constitute a reasonable approach to patient scheduling?

9. How are scheduling and productivity related?
10. What factors would you take into account in deciding whether or not to split a job?
11. Explain the term *makespan*.

TAKING STOCK

1. What general trade-offs are involved in sequencing decisions? In scheduling decisions?
2. Who needs to be involved in setting schedules?
3. How has technology had an impact on scheduling?

CRITICAL THINKING EXERCISE

One approach that can be effective in reducing the impact of production bottlenecks in a job shop or batch operations setting is to use smaller lot sizes.

a. What is the impact of a production bottleneck?
b. Explain how small lot sizes can reduce the impact of bottleneck operations.
c. What are the key trade-offs in using small lot sizes for the purpose of reducing the bottleneck effect?
d. In some cases, the location of a bottleneck will shift (i.e., sometimes it is at work station 3, another time it is at work station 12). Furthermore, there can be more than one bottleneck operation at the same time. How would these situations impact scheduling using small lots sizes?

PROBLEMS

1. Use the assignment method to determine the best way to assign workers to jobs, given the following cost information. Compute the total cost for your assignment plan.

		JOB		
		A	B	C
Worker	1	5	8	6
	2	6	7	9
	3	4	5	3

2. Rework problem 1 treating the numbers in the table as profits instead of costs. Compute the total profit.
3. Assign trucks to delivery routes so that total costs are minimized, given the cost data shown. What is the total cost?

		ROUTE				
		A	B	C	D	E
Truck	1	4	5	9	8	7
	2	6	4	8	3	5
	3	7	3	10	4	6
	4	5	2	5	5	8
	5	6	5	3	4	9

4. Develop an assignment plan that will minimize processing costs, given the information shown, and interpret your answer.

		MACHINE		
		A	B	C
Job	1	12	8	11
	2	13	10	8
	3	14	9	14
	4	10	7	12

5. Use the assignment method to obtain a plan that will minimize the processing costs in the following table under these conditions:
   a. The combination 2-D is undesirable.

b. The combinations 1-A and 2-D are undesirable.

		MACHINE				
		A	B	C	D	E
	1	14	18	20	17	18
	2	14	15	19	16	17
Job	3	12	16	15	14	17
	4	11	13	14	12	14
	5	10	16	15	14	13

6. The following table contains information concerning four jobs that are awaiting processing at a work center.

Job	Job Time (days)	Due Date (days)
A	14	20
B	10	16
C	7	15
D	6	17

a. Sequence the jobs using (1) FCFS, (2) SPT, (3) EDD, and (4) CR. Assume the list is by order of arrival.

b. For each of the methods in part *a,* determine (1) the average job flow time, (2) the average tardiness, and (3) the average number of jobs at the work center.

c. Is one method superior to the others? Explain.

7. Using the information presented in the following table, identify the processing sequence that would result using (1) FCFS, (2) SPT, (3) EDD, and (4) CR. For each method, determine (1) average job flow time, (2) average job tardiness, and (3) average number of jobs in the system. Jobs are listed in order of arrival. (*Hint:* First determine the total job time for each job by computing the total processing time for the job and then adding in the setup time. All times and due dates are in hours.)

Job	Processing Time per Unit	Units per Job	Setup Time	Due Date
a..........	0.14	45	0.7	4
b..........	0.25	14	0.5	10
c..........	0.10	18	0.2	12
d..........	0.25	40	1.0	20
e..........	0.10	75	0.5	15

8. The following table shows orders to be processed at a machine shop as of 8 A.M. Monday. The jobs have different operations they must go through. Processing times are in days. Jobs are listed in order of arrival.

a. Determine the processing sequence at the first work center using each of these rules: (1) FCFS, (2) S/O.

b. Compute the effectiveness of each rule using each of these measures: (1) average completion time, (2) average number of jobs at the work center.

Job	Processing Time (days)	Due Date (days)	Remaining Number of Operations
A	8	20	2
B	10	18	4
C	5	25	5
D	11	17	3
E	9	35	4

9. A wholesale grocery distribution center uses a two-step process to fill orders. Tomorrow's work will consist of filling the seven orders shown. Determine a job sequence that will minimize the time required to fill the orders.

	TIME (HOURS)	
Order	**Step 1**	**Step 2**
A........	1.20	1.40
B........	0.90	1.30
C........	2.00	0.80
D........	1.70	1.50
E........	1.60	1.80
F........	2.20	1.75
G........	1.30	1.40

10. The times required to complete each of eight jobs in a two-machine flow shop are shown in the table that follows. Each job must follow the same sequence, beginning with machine A and moving to machine B.
   a. Determine a sequence that will minimize makespan time.
   b. Construct a chart of the resulting sequence, and find machine B's idle time.
   c. For the sequence determined in part *a,* how much would machine B's idle time be reduced by splitting the last two jobs in half?

	TIME (HOURS)	
Job	**Machine A**	**Machine B**
a.........	16	5
b.........	3	13
c.........	9	6
d.........	8	7
e.........	2	14
f.........	12	4
g.........	18	14
h.........	20	11

11. Given the operation times provided:
   a. Develop a job sequence that minimizes idle time at the two work centers.
   b. Construct a chart of the activities at the two centers, and determine each one's idle time, assuming no other activities are involved.

	JOB TIMES (MINUTES)					
	A	**B**	**C**	**D**	**E**	**F**
Center 1	20	16	43	60	35	42
Center 2	27	30	51	12	28	24

12. A shoe repair operation uses a two-step sequence that all jobs in a certain category follow. For the group of jobs listed,
   a. Find the sequence that will minimize total completion time.
   b. Determine the amount of idle time for workstation B.
   c. What jobs are candidates for splitting? Why? If they were split, how much would idle time and makespan time be reduced?

	JOB TIMES (MINUTES)				
	a	**b**	**c**	**d**	**e**
Workstation A	27	18	70	26	15
Workstation B	45	33	30	24	10

13. The following schedule was prepared by the production manager of Marymount Metal Shop.

	CUTTING		POLISHING	
Job	**Start**	**Finish**	**Start**	**Finish**
A	0	2	2	5
B	2	6	6	9
C	6	11	11	13
D	11	15	15	20
E	15	17	20	23
F	17	20	23	24
G	20	21	24	28

Determine a schedule that will result in earlier completion of all jobs on this list.

14. The production manager must determine the processing sequence for seven jobs through the grinding and deburring departments. The same sequence will be followed in both departments. The manager's goal is to move the jobs through the two departments as quickly as possible. The foreman of the deburring department wants the SPT rule to be used to minimize the work-in-process inventory in his department.

	PROCESSING TIME (HOURS)	
Job	**Grinding**	**Deburring**
A	3	6
B	2	4
C	1	5
D	4	3
E	9	4
F	8	7
G	6	2

a. Prepare a schedule using SPT for the grinding department.
b. What is the flow time in the grinding department for the SPT sequence? What is the total time needed to process the seven jobs in both the grinding and deburring departments?
c. Determine a sequence that will minimize the total time needed to process the jobs in both departments. What flow time will result for the grinding department?
d. Discuss the trade-offs between the two alternative sequencing arrangements. At what point would the production manager be indifferent concerning the choice of sequences?

15. A foreman has determined processing times at a work center for a set of jobs and now wants to sequence them. Given the information shown, do the following:
a. Determine the processing sequence using (1) FCFS, (2) SPT, (3) EDD, and (4) CR. For each sequence, compute the average job tardiness, the average flow time, and the average number of jobs at the work center. The list is in FCFS order.
b. Using the results of your calculations in part *a,* show that the average flow time and the average number of jobs measures are equivalent for all four sequencing rules.
c. Determine the processing sequence that would result using the S/O rule.

Job	Job Time (days)	Due Date	Operations Remaining
a	4.5	10	3
b	6.0	17	4
c	5.2	12	3
d	1.6	27	5
e	2.8	18	3
f	3.3	19	1

16. Given the information in the following table, determine the processing sequence that would result using the S/O rule.

Job	Remaining Processing Time (days)	Due Date	Remaining Number of Operations
a	5	8	2
b	6	5	4
c	9	10	4
d	7	12	3
e	8	10	2

17. Given the following information on job times and due dates, determine the optimal processing sequence using (1) FCFS, (2) SPT, (3) EDD, and (4) CR. For each method, find the average job flow time and the average job tardiness.

Job	Job Time (hours)	Due Date (hours)
a	3.5	7
b	2.0	6
c	4.5	18
d	5.0	22
e	2.5	4
f	6.0	20

18. The Budd Gear Co. specializes in heat-treating gears for automobile companies. At 8 A.M., when Budd's shop opened today, five orders (listed in order of arrival) were waiting to be processed.

Order	Order Size (units)	Per Unit Time in Heat Treatment (minutes/unit)	Due Date (min. from now)
A	16	4	160
B	6	12	200
C	10	3	180
D	8	10	190
E	4	1	220

a. If the due date rule is used, what sequence should be used?
b. What will be the average job tardiness?
c. What will be the average number of jobs in the system?
d. Would the SPT rule produce better results in terms of lateness?

19. The following table contains order-dependent setup times for three jobs. Which processing sequence will minimize the total setup time?

		Setup time (hrs.)	Following job's setup time (hrs.) A	B	C
Preceding Job	A	2	—	3	5
	B	3	8	—	2
	C	2	4	3	—

20. The following table contains order-dependent setup times for three jobs. Which processing sequence will minimize the total setup time?

		Setup time (hrs.)	Following job's setup time (hrs.) A	B	C
Preceding Job	A	2.4	—	1.8	2.2
	B	3.2	0.8	—	1.4
	C	2.0	2.6	1.3	—

21. The following table contains order-dependent setup times for four jobs. For safety reasons, job C cannot follow job A, nor can job A follow job C. Determine the processing sequence that will minimize the total setup time. (*Hint:* There are 12 alternatives.)

			Following job's setup time (hrs.)			
		Setup time (hrs.)	**A**	**B**	**C**	**D**
	A	2	—	5	x	4
Preceding	**B**	1	7	—	3	2
Job	**C**	3	x	2	—	2
	D	2	4	3	6	—

22. Given this information on planned and actual inputs and outputs for a service center, determine the work backlog for each period. The beginning backlog is 12 hours of work. The figures shown are standard hours of work.

		PERIOD				
		1	**2**	**3**	**4**	**5**
Input	Planned	24	24	24	24	20
	Actual	25	27	20	22	24
Output	Planned	24	24	24	24	23
	Actual	24	22	23	24	24

23. Determine the minimum number of workers needed, and a schedule for the following staffing requirements, giving workers two consecutive days off per cycle (not including Sunday).

Day	Mon	Tue	Wed	Thu	Fri	Sat
Staff needed	2	3	1	2	4	3

24. Determine the minimum number of workers needed, and a schedule for the following staffing requirements, giving workers two consecutive days off per cycle (not including Sunday).

Day	Mon	Tue	Wed	Thu	Fri	Sat
Staff needed	3	4	2	3	4	5

25. Determine the minimum number of workers needed, and a schedule for the following staffing requirements, giving workers two consecutive days off per cycle (not including Sunday).

Day	Mon	Tue	Wed	Thu	Fri	Sat
Staff needed	4	4	5	6	7	8

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PART SIX

Supply Chain Management

Supply chain management refers to management of all of the functions, facilities, and activities, both within and external to a business organization, that make up a value chain.

CHAPTER 16

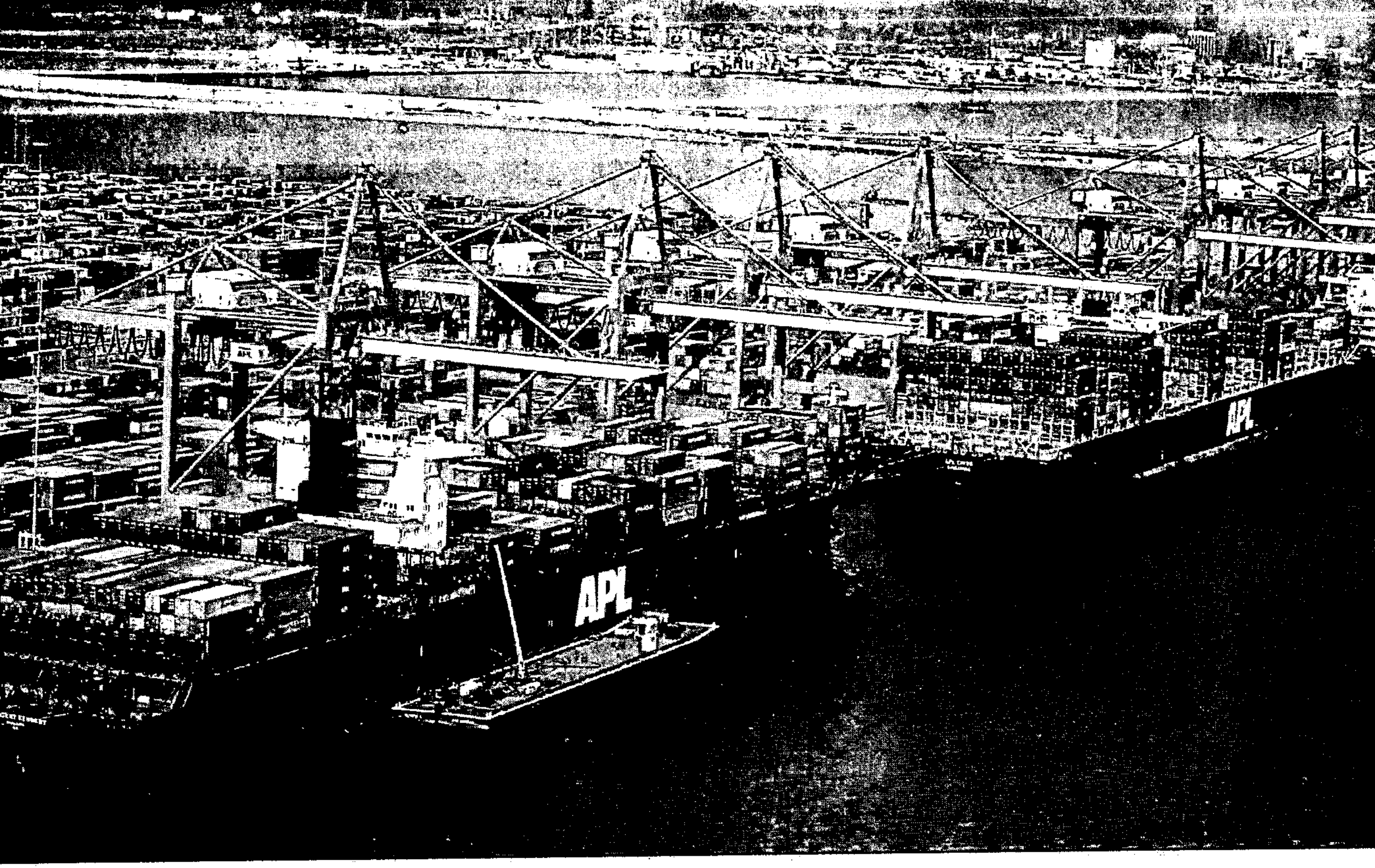
Supply Chain Management

LEARNING OBJECTIVES

After completing this chapter, you should be able to:

1 Explain what a supply chain is.
2 Explain the need to manage a supply chain and the potential benefits of doing so.
3 Explain the increasing importance of outsourcing.
4 State the objective of supply chain management.
5 List the elements of supply chain management.
6 Identify the strategic, tactical, and operations issues in supply chain management.
7 Describe the bullwhip effect and the reasons why it occurs.
8 Explain the value of strategic partnering.
9 Discuss the importance of supply chain management for e-commerce.
10 Discuss the critical importance of information exchange across a supply chain.
11 Outline the key steps, and potential challenges, in creating an effective supply chain.
12 Explain the importance of the purchasing function in business organizations.
13 Describe the responsibilities of purchasing.
14 Explain the term *value analysis.*
15 Identify several guidelines for ethical behavior in purchasing.
16 Explain how supplier partnerships can be advantageous to an organization.

CHAPTER OUTLINE



The Wegmans supermarket chain (see the Wegmans tour in Chapter 1) is often mentioned as being the best-run supermarket chain in the United States. It's now being mentioned for its leadership in supply chain management in the grocery industry. Wegmans employs about 37,000 people. When a Wegmans spokesperson was asked how many of its people work in its supply chain, the spokesperson replied "37,000."

The fact of the matter is that most if not all of the people who work in any business organization are somehow involved with the supply chain. And no matter where your career takes you, in every job you do, you'll be involved in one (or more) supply chain(s).

This chapter covers the basics of supply chain management. Among other things, you will learn what a supply chain is, why there is a need for supply chain management, what the key elements in managing a supply chain are, what steps are necessary in creating an effective supply chain, and what some of the challenges are in supply chain management.

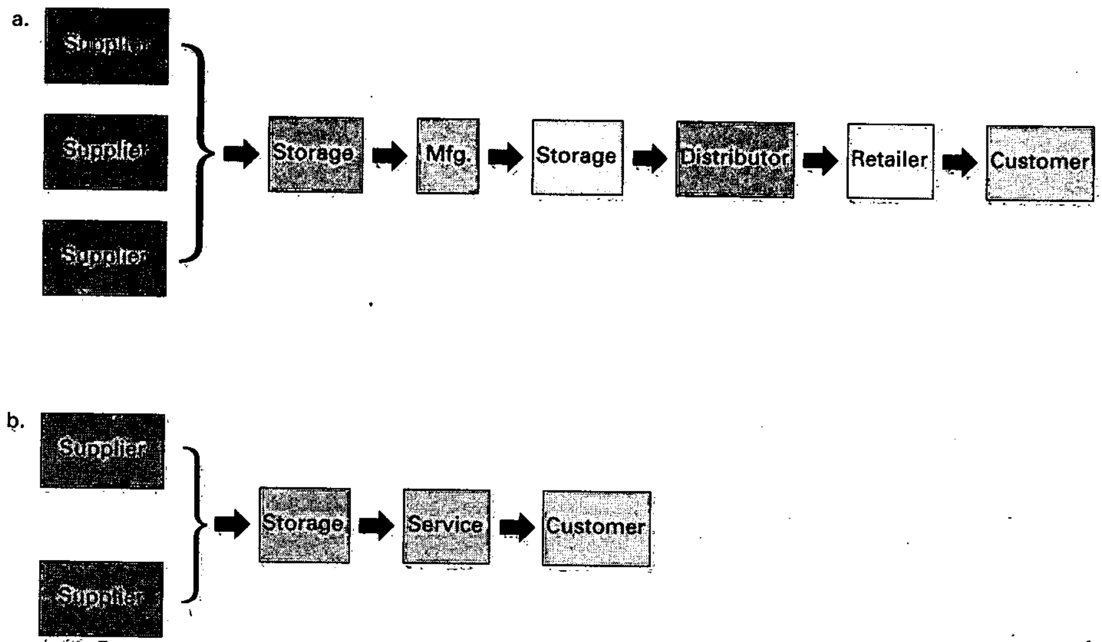
INTRODUCTION

A **supply chain** is the sequence of organizations—their facilities, functions, and activities—that are involved in producing and delivering a product or service. The sequence begins with basic suppliers of raw materials and extends all the way to the final customer. Facilities include warehouses, factories, processing centers, distribution centers, retail outlets, and offices. Functions and activities include forecasting, purchasing, inventory management, information management, quality assurance, scheduling, production, distribution, delivery, and customer service. There are two kinds of movement in these systems: the physical movement of material, generally in the direction of the end of the chain (although not all material starts at the beginning of the chain), and exchange of information, which moves in both directions along the chain.

supply chain A sequence of organizations—their facilities, functions, and activities—that are involved in producing and delivering a product or service.

FIGURE 16.1

Typical supply chains



Every business organization is part of at least one supply chain, and many are part of multiple supply chains. Often the number and type of organizations in a supply chain are determined by whether the supply chain is manufacturing or service oriented. Figure 16.1 illustrates typical manufacturing and service supply chains.

Supply chains are sometimes referred to as *value chains*, a term that reflects the concept that value is added as goods and services progress through the chain. Supply or value chains are typically comprised of separate business organizations, rather than just a single organization. Moreover, the supply or value chain has two components for each organization: a supply component and a demand component. The supply component starts at the beginning of the chain and ends with the internal operations of the organization. The demand component of the chain starts at the point where the organization's output is delivered to its immediate customer and ends with the final customer in the chain. The *demand chain* is the sales and distribution portion of the value chain. The length of each component depends on where a particular organization is in the chain; the closer the organization is to the final customer, the shorter its demand component and the longer its supply component.

All organizations, regardless of where they are in the chain, must deal with supply and demand issues. The goal of supply chain management is to link all components of the supply chain so that market demand is met as efficiently as possible across the entire chain. This requires matching supply and demand at each stage of the chain. Note that except for the beginning supplier(s) and the final customer(s), the organizations in a supply chain are both customers and suppliers.

Figure 16.2 presents another illustration of a supply chain, repeating a diagram you might remember from Chapter 1. While the diagrams shown in Figure 16.1 and 16.2 are helpful in conceptualizing supply chains, they are, in fact, simplified versions of actual supply chains. Real supply chains are longer and they are interconnected with other supply chains, making them much more complex. For example, the farmer isn't the beginning of the chain in Figure 16.2; the farmer has suppliers for seeds and equipment such as tractors. Tractors are made in a factory, and that factory has its own supply chain. Similarly, the bakery has supply chains for other ingredients that go into baking bread, such as yeast and salt, and for its baking equipment.

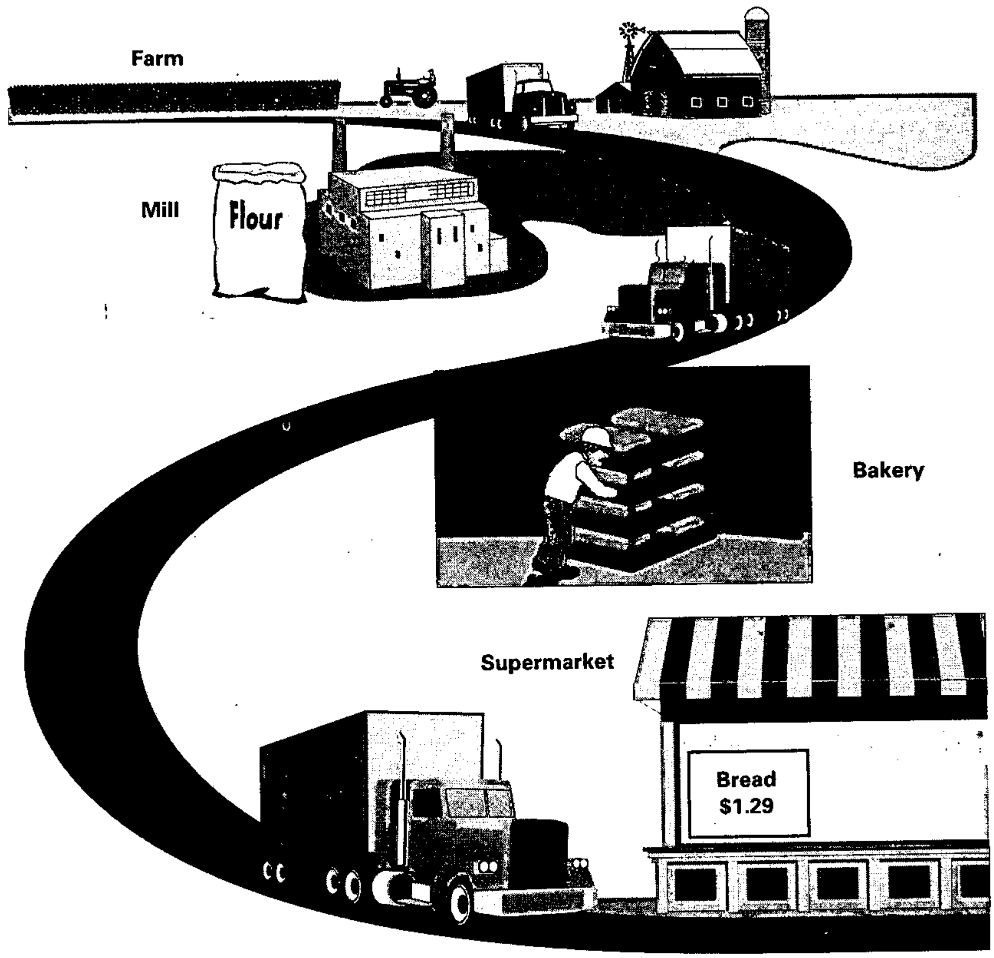


FIGURE 16.2
A farm-to-market supply chain

So, too, do each of the trucking companies and the retail stores that sell the bread. In effect, a "supply chain" is a complex "supply network."

THE NEED FOR SUPPLY CHAIN MANAGEMENT

In the past, most organizations did little to manage their supply chains. Instead, they tended to concentrate on their own operations and on their immediate suppliers. However, a number of factors make it desirable for business organizations to actively manage their supply chains. The major factors are

1. *The need to improve operations.* During the last decade, many organizations adopted practices such as lean production and TQM. As a result, they were able to achieve improved quality while wringing much of the excess costs out of their systems. Although there is still room for improvement, for many organizations, the major gains have been realized. Opportunity now lies largely with procurement, distribution, and logistics—the supply chain.

2. *Increasing levels of outsourcing.* Organizations are increasing their levels of **outsourcing**, buying goods or services instead of producing or providing them themselves. As outsourcing increases, organizations are spending increasing amounts on supply-related activities (wrapping, packaging, moving, loading and unloading, and sorting). A significant amount of the cost and time spent on these and other related activities may be unnecessary.

outsourcing Buying goods or services instead of producing or providing them in-house.

3. *Increasing transportation costs.* Transportation costs are increasing, and they need to be more carefully managed.

4. *Competitive pressures.* Competitive pressures have led to an increasing number of new products, shorter product development cycles, and increased demand for customization. And

in some industries, most notably consumer electronics, product life cycles are relatively short. Added to this are adoption of quick-response strategies and efforts to reduce lead times.

5. *Increasing globalization.* Increasing globalization has expanded the physical length of supply chains. A global supply chain increases the challenges of managing a supply chain. Having far-flung customers and/or suppliers means longer lead times and greater opportunities for disruption of deliveries. Often currency differences and monetary fluctuations are factors, as well as language and cultural differences.

6. *Increasing importance of e-commerce.* The increasing importance of e-commerce has added new dimensions to business buying and selling and has presented new challenges.

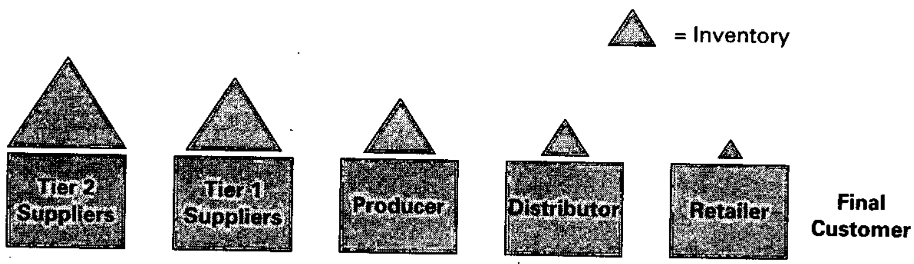
7. *The complexity of supply chains.* Supply chains are complex; they are dynamic, and they have many inherent uncertainties that can adversely affect the supply chain, such as inaccurate forecasts, late deliveries, substandard quality, equipment breakdowns, and canceled or changed orders.

8. *The need to manage inventories.* Inventories play a major role in the success or failure of a supply chain, so it is important to coordinate inventory levels throughout a supply chain. Shortages can severely disrupt the timely flow of work and have far-reaching impacts, while excess inventories add unnecessary costs. It would not be unusual to find inventory shortages in some parts of a supply chain and excess inventories in other parts of the same supply chain. Another very important inventory phenomenon that can occur without good supply chain management is the **bullwhip effect**: Inventory stockpiles become progressively larger looking backward through the chain from the final customer toward the beginning of the supply chain. This phenomenon is illustrated in Figure 16.3. The bullwhip effect increases inventory costs and, hence, final costs.

bullwhip effect Inventories become progressively larger looking backward through the supply chain.

FIGURE 16.3

The bullwhip effect on supply chain inventories



BENEFITS OF EFFECTIVE SUPPLY CHAIN MANAGEMENT

Effective supply chain management offers numerous benefits. For example, Campbell Soup doubled its inventory turnover rate, Hewlett-Packard cut deskjet printer supply costs by 75 percent, Sport Obermeyer doubled profits and increased sales by 60 percent in two years, and National Bicycle increased its market share from 5 percent to 29 percent[1]. And effective supply chain management helped Wal-Mart become the largest and most profitable retailer in the world!

Generally, benefits of effective supply chain management include lower inventories, lower costs, higher productivity, greater agility, shorter lead times, higher profits, and greater customer loyalty.

www.campbellsoups.com

www.hp.com

www.obermeyer.com

www.walmart.com

ELEMENTS OF SUPPLY CHAIN MANAGEMENT

Supply chain management involves coordinating activities across the supply chain. Central to this is taking customer demand and translating it into corresponding activities at each level of the supply chain.

[1]Marshall Fisher, "What Is the Right Supply Chain for Your Product?" *Harvard Business Review*, March/April 1997, pp. 105–16.

TABLE 16.1
Elements of supply chain management

Element	Typical Issues	Chapter(s)
Customers	Determining what products and/or services customers want.	3, 4
Forecasting	Predicting the quantity and timing of customer demand.	3
Design	Incorporating customers, wants, manufacturability, and time to market.	4
Capacity planning	Matching supply and demand.	5, 12
Processing	Controlling quality, scheduling work.	10, 15
Inventory	Meeting demand requirements while managing the costs of holding inventory.	10, 11, 12
Purchasing	Evaluating potential suppliers, supporting the needs of operations on purchased goods and services.	This chapter
Suppliers	Monitoring supplier quality, on-time delivery, and flexibility; maintaining supplier relations.	This chapter
Location	Determining the location of facilities.	8
Logistics	Deciding how to best move information and materials.	This chapter

The key elements of supply chain management are listed in Table 16.1. The first element, customers, is the driving element. Typically, marketing is responsible for determining what customers want as well as forecasting the quantities and timing of customer demand. Product and service design must match customer wants with operations capabilities.

Processing occurs in each component of the supply chain; it is the core of each organization. The major portion of processing occurs in the organization that produces the product or service for the final customer (the organization that assembles the computer, services the car, etc.). A major aspect of this for both the internal and external portions of a supply chain is scheduling.

Inventory is a staple in most supply chains. Balance is the main objective; too little causes delays and disrupts schedules, but too much adds unnecessary costs and limits flexibility.

Purchasing is the link between an organization and its suppliers. It is responsible for obtaining goods and/or services that will be used to produce products or provide services for the organization's customers. Purchasing selects suppliers, negotiates contracts, establishes alliances, and acts as liaison between suppliers and various internal departments.

The supply portion of a value chain is made up of one or more suppliers, all links in the chain, and each one capable of having an impact on the effectiveness—or the ineffectiveness—of the supply chain. Moreover, it is essential that the planning and execution be carefully coordinated between suppliers and all members of the demand portion of their chains.

Location can be a factor in a number of ways. Where suppliers are located can be important, as can location of processing facilities. Nearness to market, or nearness to sources of supply, or nearness to both may be critical. Also, delivery time and cost are usually affected by location.

Logistics is discussed in the next section.

LOGISTICS

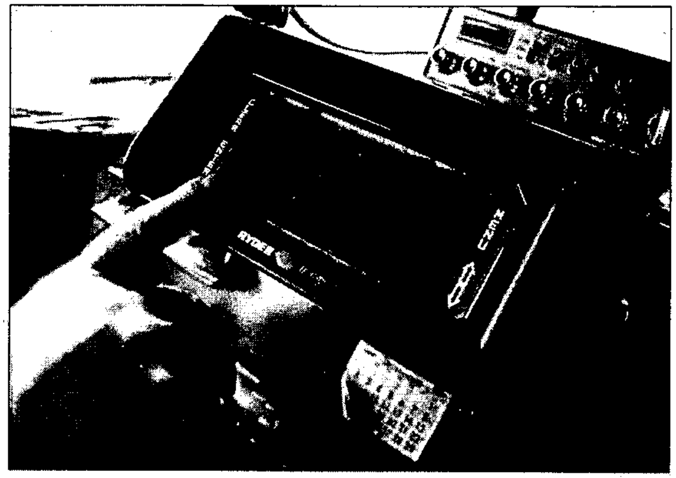
Logistics refers to the movement of materials and information in a supply chain. Materials include all of the physical items used in a production process. In addition to raw materials and work in process, there are support items such as fuels, equipment, parts, tools, lubricants, office supplies, and more. Logistics includes movement within a facility, overseeing incoming and outgoing shipments of goods and materials, and information flow throughout the supply chain.

logistics The movement of materials and information in a supply chain.

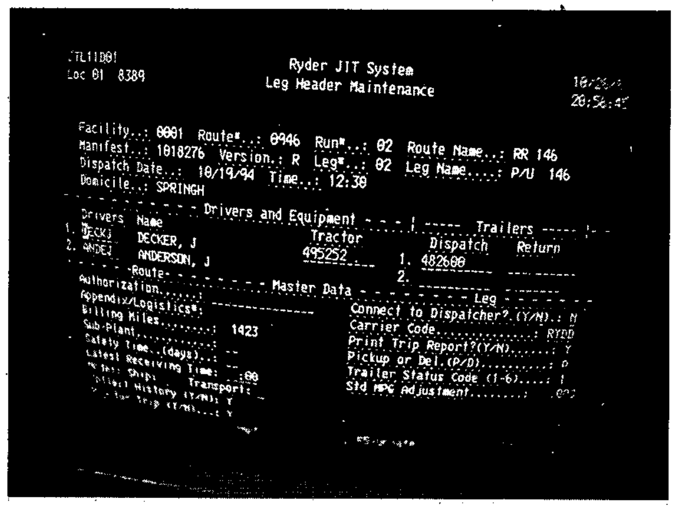
Movement within a Facility

Movement of goods within a manufacturing facility is part of production control. Figure 16.4 shows the many steps where materials move within a manufacturing facility:

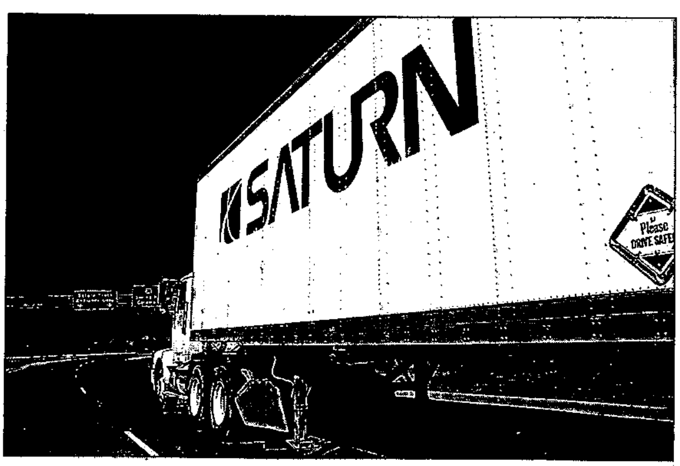
Ryder company delivers (in trucks labeled 'Saturn') bins of speedometers and odometers to Saturn's Spring Hill, Tennessee, plant. Thursday, 9 A.M.: A Ryder truck arrives at a Saturn supplier in Winchester, Virginia.



Drivers check the onboard computer, which provides destination and routing information, along with estimated travel times.



Spring Hill, Tennessee, Friday, 3 A.M.: After parking the trailer in a computer-assigned spot in Ryder's switching yard two miles from the Saturn plant, the driver downloads a key-shaped floppy disk from the onboard computer into Ryder's mainframe, which generates performance reports for Saturn.



12:50 P.M.: The trailer approaches the Saturn plant.

12:53 P.M.: The trailer arrives at one of Saturn's 56 receiving docks just in time for Saturn workers to unload the bins and unwrap the pre-inspected instruments to ready them for the production line.

1. From incoming vehicles to receiving.
2. From receiving to storage.
3. From storage to the point of use (e.g., a work center).
4. From one work center to the next or to temporary storage.
5. From the last operation to final storage.
6. From storage to packaging/shipping.
7. From shipping to outgoing vehicles.

In some instances, the goods being moved are supplies; in other instances, the goods are actual products or partially completed products; and in still other instances, the goods are raw materials or purchased parts.

Movement of materials must be coordinated to arrive at the appropriate destinations at appropriate times. Workers and supervisors must take care so that items are not lost, stolen, or damaged during movement.

Incoming and Outgoing Shipments

Overseeing the shipment of incoming and outgoing goods comes under the heading of **traffic management**. This function handles schedules and decisions on shipping method and times, taking into account costs of various alternatives, government regulations, the needs of the organization relative to quantities and timing, and external factors such as potential shipping delays or disruptions (e.g., highway construction, truckers' strikes).

traffic management Overseeing the shipment of incoming and outgoing goods.

Computer tracking of shipments often helps to maintain knowledge of the current status of shipments as well as to provide other up-to-date information on costs and schedules.

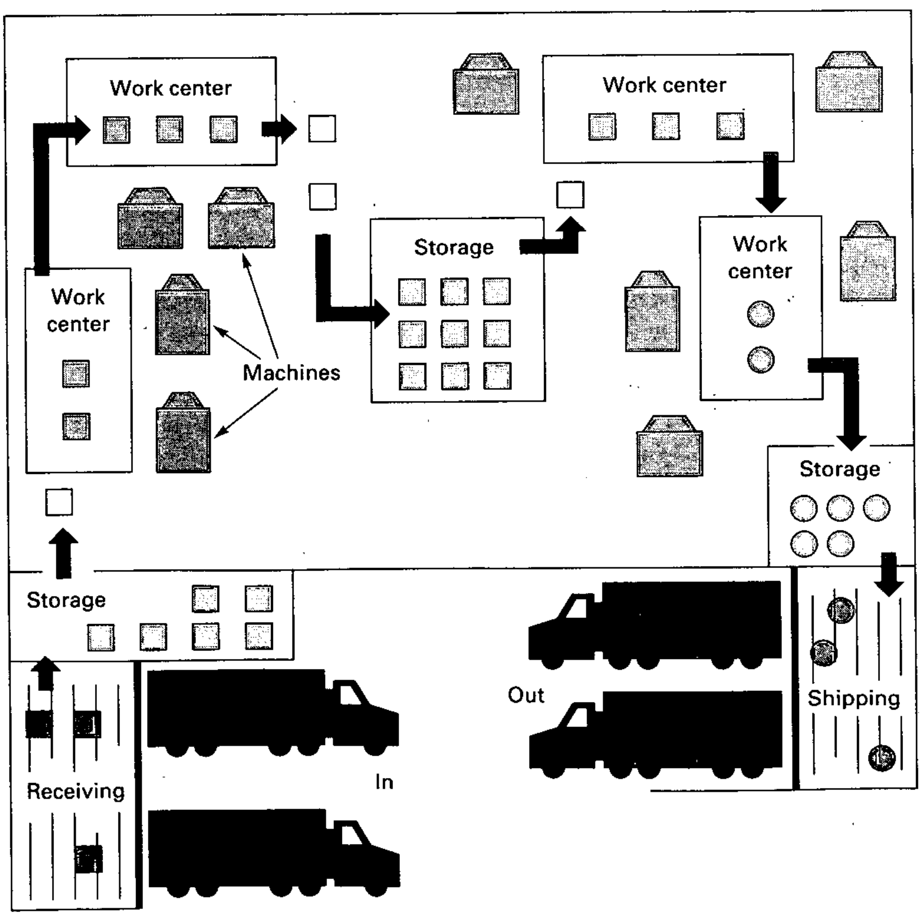


FIGURE 16.4

Movement within a facility

Distribution Requirements Planning

distribution requirements planning (DRP) A system for inventory management and distribution planning.

Distribution requirements planning (DRP) is a system for inventory management and distribution planning. It is especially useful in multiechelon warehousing systems (factory and regional warehouses). It extends the concepts of material requirements planning (MRP) to multiechelon warehouse inventories, starting with demand at the end of a channel and working back through the warehouse system to obtain time-phased replenishment schedules for moving inventories through the warehouse network. In effect, management uses DRP to plan and coordinate transportation, warehousing, workers, equipment, and financial flows.

Electronic Data Interchange

electronic data interchange (EDI) The direct transmission of interorganizational transactions, computer-to-computer, including purchase orders, shipping notices, and debit or credit memos.

Electronic data interchange (EDI) is the direct, computer-to-computer transmission of interorganizational transactions, including purchase orders, shipping notices, debit or credit memos, and more. Among the reasons companies are increasingly using EDI are

- Increased productivity.
- Reduction of paperwork.
- Lead time and inventory reduction.
- Facilitation of just-in-time (JIT) systems.
- Electronic transfer of funds.
- Improved control of operations.
- Reduction in clerical labor.
- Increased accuracy.

The use of EDI linkages with other organizations can be part of a strategy to achieve a competitive advantage by leveraging logistics performance. In addition, in some JIT environments, EDI serves as the signal for replenishment from the manufacturer to the supplier.

There are many applications of EDI in the retail industries involving electronic communication between retailers and vendors. Dubbed *quick response*, the approach is based on scanning bar codes and transmitting that information to vendors. The purpose is to create a just-in-time replenishment system that is keyed to customer buying patterns. Retailers use Universal Product Code (UPC) scanning or point-of-sale (POS) scanning at the registers, which use price-look-up (PLU) to track customer buying.

Quick-response approaches have several benefits. Among them are reduced dependency on forecasts and the ability to achieve a closer match between supply and demand. In addition, there is the strong possibility of saving on inventory carrying costs.

Wal-Mart has a satellite network for electronic data interchange that allows vendors to directly access point-of-sale data in real time, enabling them to improve their forecasting and inventory management. Wal-Mart also uses the system for issuing purchase orders and receiving invoices from its vendors.

efficient consumer response (ECR) A quick response initiative using EDI and bar codes specific to the food industry.

Efficient consumer response (ECR) is a supply chain management initiative specific to the food industry. It reflects companies' efforts to achieve quick response using EDI and bar codes. The following newsclip describes how RFID tags could contribute to this.

RF Tags: Keeping the Shelves Stocked

NEWSCLIP

In the consumer packaged-goods industry, the supply chain works smoothly when sales are steady, but it often breaks down when confronted by a sudden surge in demand. RFID tags could change that by providing real-time information about what's happening on store shelves. Here's how the system would work:

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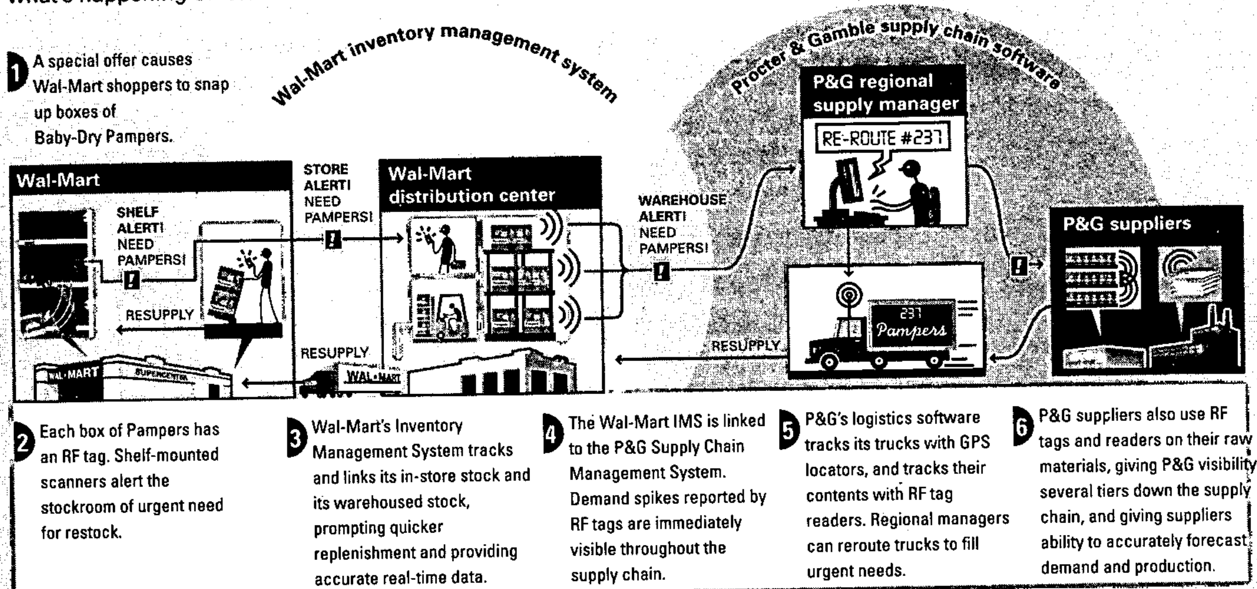
RF Tags: Keeping the Shelves Stocked

The supply chain of the consumer packaged goods industry works well when sales are steady, but it often breaks down when confronted by a sudden surge in demand. RF Tags could change that by providing real-time information about what's happening on store shelves. Here's how the system would work:



Source: as seen in Business 2.0 Copyright © 2002, Xplanations. Used with permission.

3-PL

3-PL (third-party logistics) is the term used to describe the outsourcing of logistics management. Companies are turning over warehousing and distribution to companies that specialize in these areas. Among the potential benefits of this are taking advantage of specialists' knowledge, their well-developed information system, and their ability to obtain more favorable shipping rates, and, for the company, being able to focus more on its core business.

Rise of the 3PL

READING

Over 40% of companies plan to outsource more software from third-party logistics providers (3PLs) over the next five years, according to "Beyond Software: Maximizing Value Via Outsourcing," a new strategic report developed by ARC Advisory Group and *SUPPLY CHAIN TECHNOLOGY NEWS.* Outsourcing is becoming the preferred choice for many companies, as evidenced by the strong growth of 3PLs and the increasing number of solution vendors that are offering hosted solutions.

Major companies such as Ford Motor, Procter & Gamble, General Mills, DuPont and CVS are all outsourcing various logistics-related tasks from transportation management to global trade management to fleet management. In the case of Ford, for instance, the automaker uses a 3PL to manage its import and export trade processes throughout North America.

ARC and *SCTN* conducted a survey of manufacturers and retailers to better understand their perspective of this emerging trend.

"Since software is generally coupled with specific business processes, it's not surprising that companies are . . . expecting 3PLs to provide a certain level of IT sophistication," explains ARC analyst Adrian Gonzalez, author of the report. "Hence, technology is becoming a competitive differentiator for 3PLs, especially for small and mid-size players that want to level the playing field with 'the big boys.' Technology also enables 3PLs to scale their operations without incurring additional overhead, assets and other costs. Simply stated, it allows them to do more with less."

Key findings of the report indicate that:

- Large companies are more inclined to outsource than smaller ones, but both want to maintain some level of control, particularly for solutions/business process that directly impact customer and supplier relationships.

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- When companies decide to outsource, they generally prefer to bundle the technology with managed services, primarily from a 3PL (as opposed to a software vendor).
- If a company decides to outsource just the technology, a software vendor is preferred over a 3PL.

Questions

1. Why do you think that large companies are more inclined to outsource than smaller ones?
2. How important is technology in the 3PL decision? Why do you think this is?

Source: Excerpted from "The Rise of the 3PL," totalmedia.com.

E-COMMERCE

e-commerce The use of electronic technology to facilitate business transactions.

www.ups.com

www.fedex.com

The commercial blossoming of the Internet has led to an explosion of Internet-related activities, many of which have a direct impact on organizations' supply chains, even if those organizations aren't themselves users of the Internet. **E-commerce** refers to the use of electronic technology to facilitate business transactions. E-commerce involves the interaction of different business organizations as well as the interaction of individuals with business organizations. Applications include Internet buying and selling, e-mail, order and shipment tracking, and electronic data interchange. In addition, companies use e-commerce to promote their products or services, and to provide information about them. Delivery firms have seen the demand for their services increase dramatically due to e-commerce. Among them are giants UPS and FedEx.

Table 16.2 lists some of the numerous advantages of e-commerce.

There are two essential features of e-commerce businesses: the website and order fulfillment. Companies may invest considerable time and effort in front-end design (the website), but the back end (order fulfillment) is at least as important. It involves order processing, billing, inventory management, warehousing, packing, shipping, and delivery.

Many of the problems that occur with Internet selling are supply-related. The ability to order quickly creates an expectation in customers that the remainder of the process will proceed smoothly and quickly. But the same capability that enables quick ordering also enables demand fluctuations that can inject a certain amount of chaos to the system, almost guaranteeing that

TABLE 16.2
Advantages of e-commerce

Companies and publishers have a global presence and the customer has global choices and easy access to information.
Companies can improve competitiveness and quality of service by allowing access to their services any place, any time. Companies also have the ability to monitor customers' choices and requests electronically.
Companies can analyze the interest in various products based on the number of hits and requests for information.
Companies can collect detailed information about clients' preferences, which enables mass customization and personalized products. An example is the purchase of PCs over the web, where the buyer specifies the final configuration.
Supply chain response times are shortened. The biggest impact is on products that can be delivered directly on the web, such as forms of publishing and software distribution.
The roles of the intermediary and sometimes the traditional retailer or service provider are reduced or eliminated entirely in a process called *disintermediation.* This process reduces costs and adds alternative purchasing options.
Substantial cost savings and substantial price reductions related to the reduction of transaction costs can be realized. Companies that provide purchasing and support through the web can save significant personnel costs.
E-commerce allows the creation of virtual companies that distribute only through the web, thus reducing costs. Amazon.com and other net vendors can afford to sell for a lower price because they do not need to maintain retail stores and, in many cases, warehouse space.
The playing field is leveled for small companies that lack significant resources to invest in infrastructure and marketing.

Source: Reprinted by permission from David Simchi-Levi, Philip Kaminsky, and Edith Simchi-Levi, *Designing and Managing the Supply Chain: Concepts, Strategies, and Case Studies* (New York: Irwin/McGraw-Hill, 2000), p. 235.

there won't be a smooth or quick delivery. Oftentimes the rate at which orders come in via the Internet greatly exceeds an organization's ability to fulfill them. Not too long ago, Toys "R" Us had that experience during the busy Christmas season; it ended up offering thousands of disappointed customers a $100 coupon to make up for it.

In the early days of Internet selling, many organizations thought they could avoid bearing the costs of holding inventories by acting solely as intermediaries, having their suppliers ship directly to their customers. Although this approach worked for some companies, it failed for others, usually because suppliers ran out of certain items. This led some companies to rethink the strategy. Industry giants such as Amazon.com, barnesandnoble.com, and online grocer Webvan Group built huge warehouses around the country so they could maintain greater control over their inventories. Still others are outsourcing fulfillment, turning over that portion of their business to third-party fulfillment operators such as former catalog fulfillment company Fingerhut, now a unit of Federated Department Stores.

Using third-party fulfillment means losing control over fulfillment. It might also result in fulfillers substituting their standards for the company they are serving, and using the fulfiller's shipping price structure. On the other hand, an e-commerce company may not have the resources or infrastructure to do the job itself. Another alternative might be to form a strategic partnership with a "bricks and mortar" company. This can be a quick way to jump-start an e-commerce business. In any case, somewhere in the supply chain there has to be a bricks-and-mortar facility.

Desperately Seeking E-Fulfillment

NEWSCLIP

www.fingerhut.com

Fingerhut is now a major e-commerce fulfillment player, thanks as much to its massive data warehouse of customer information as to its four million square feet of high tech warehouse space.

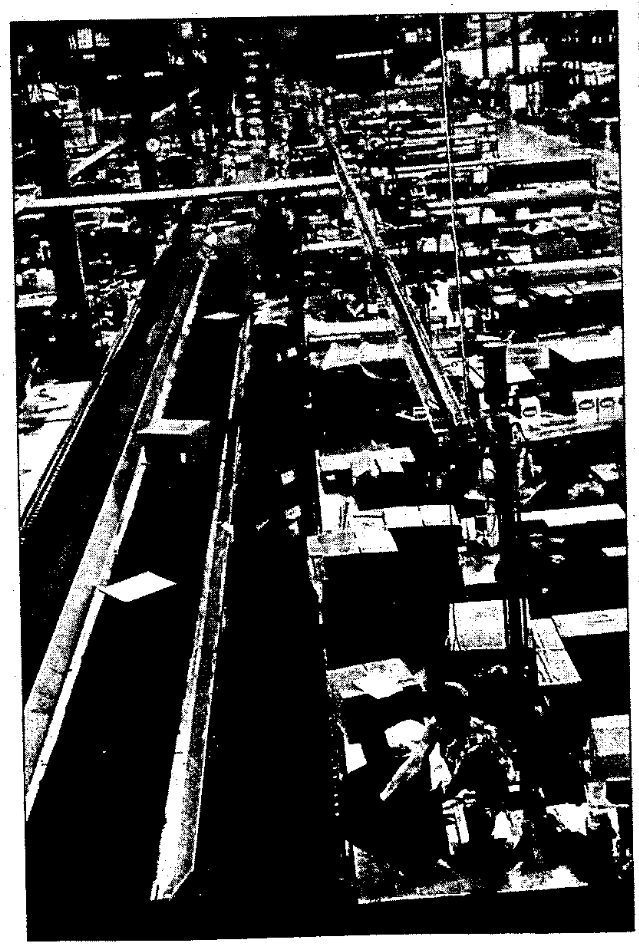
In addition to handling its own business, Fingerhut handles the back end of other high-volume retailers, such as Wal-Mart and eToys. Their massive warehouse in St. Cloud, MN, can process as many as 30,000 items per hour.

Big shippers like UPS and Federal Express have also successfully branched into e-commerce fulfillment. In addition to their traditional shipping niche, they'll warehouse your inventory for you, handle all back-end tasks, and offer complete solutions including web site design, development, and hosting. Their e-commerce edge came not only from their overnight, single-order delivery infrastructure, but also from having already developed package-tracking software.

Hiring a fulfillment giant is de rigueur these days for huge "click and bricks" retailers like Wal-Mart and Pier One, who have to switch in a hurry from their old operating model of moving big pallets of goods to stores to moving single items to individuals.

Third-party fulfillers are treasured for their efficiencies and advanced technology. But some can be unresponsive and not always capable of supporting [clients'] software. There has also been some grumbling in *Barrons* that the big third-party fulfillers are doomed middlemen, a mere transitory phase for e-commerce.

Source: Excerpted from Judith Silverstein, "Desperately Seeking E-Fulfillment," *Digital Chicago*, November/December 1999, pp. 29–30.



Behind the scenes of e-commerce: Order processing and fulfillment at Fingerhut.

TABLE 16.3
B2B marketplace enablers

Type	Description
Financial	Provide financial and other resources for web-enhanced commerce.
Technology	Provide software, applications, and expertise necessary to create B2B marketplace.

Source: Adapted from *Forbes*, July 2000.

A growing portion of e-commerce involves business-to-business (B2B) commerce rather than business-to-consumer commerce. To facilitate business-to-business commerce, B2B marketplaces are created. Table 16.3 describes B2B marketplace enablers.

B2B exchanges can improve supply chain visibility to trading partners from a single point of access, facilitating the development of common standards and data formats for schedules, product codes, location codes, and performance criteria. And e-businesses focusing on transportation services can benefit from having an efficient hub for collaboration between shippers and transportation providers, helping to translate customer shipment forecasts into more predictable demand for equipment, and enabling carriers to deploy their equipment more effectively.

CREATING AN EFFECTIVE SUPPLY CHAIN

Creating an effective supply chain requires linking the market, distribution channels, processing, and suppliers. The design of a supply chain should enable all participants in the chain to achieve significant gains, hence giving them an incentive to cooperate. It should enable participants to (1) share forecasts, (2) determine the status of orders in real time, and (3) access inventory data of partners.

E-procurement, as described in the Reading "E-Procurement at IBM," is becoming increasingly common.

E-Procurement at IBM

READING

www.ibm.com

"In 1999, IBM did what would seem to be a near impossible task. It began doing business with 12,000 suppliers over the Internet—sending purchase orders, receiving invoices and paying suppliers, all using the World Wide Web as its transaction-processing network."

Setting up 12,000 suppliers to do business on the Internet was relatively easy compared to the resistance of suppliers to link to IBM via EDI (electronic data interchange). Suppliers who didn't have large contracts with IBM balked at EDI because of the expense of special software and a VAN (value-added network) that were needed to do EDI. No such problem with using the Internet: suppliers don't need special software or a costly VAN to do business with IBM.

The Internet's simplicity reduces costs for IBM and its suppliers. IBM estimated that it saved $500 million in 1999 by moving procurement to the Web, and believes that is only the tip of the iceberg. Much of the savings came from eliminating intermediaries. IBM uses the Web to manage multiple tiers of suppliers and as a tool to work with suppliers to improve quality and reduce costs.

But cost reduction was not the only reason IBM switched to Internet procurement. Web-based procurement is a key part of its supplier management strategy: IBM sees great value in using the Internet to collaborate with suppliers and tap into their expertise much more rapidly than previously. "The Internet will also allow IBM to collaborate with suppliers over scheduling issues. If the company wants to increase production of a certain product it will be able to check with component suppliers and determine if suppliers can support the increase. If there are schedule cutbacks, [it] will be able to notify suppliers almost instantaneously and excess inventory can be avoided."

And although supply chains are viewed as sequential, IBM doesn't necessarily want to manage them that way. Rather, it wants to use the Internet to manage multiple tiers of suppliers simultaneously. An example of this is how it deals with CMs (contract manufacturers). The company sends forecasts and purchase orders to the CMs for the printed circuit boards they supply. It also gives all the component manufacturers the requirements and they ship parts directly to the CM. The company

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estimates it saved in excess of $150 million in 1999. "The savings were the difference between contract manufacturers' price for components used on the boards and IBM's price that it had negotiated with component suppliers."

Because the Internet is becoming crucial to IBM's supplier-management strategies, IBM is trying to make it easier for suppliers to do business over the Web. The company has developed a Web-based portal to provide a single entry point to IBM. As is the case with most large companies, IBM has multiple interfaces with its suppliers, including engineering, quality, as well as purchasing, and typically suppliers have to connect to separate URLs (Universal Resource Locators) in a company. IBM's portal provides a single point of entry for suppliers, making it easier for suppliers to do business with IBM and increasing the speed of the supply chain. Speed is vitally important in the electronics industry due to very short product life cycles. If products don't get to the market quickly, most of the profit opportunity is lost.

Still another benefit envisioned by IBM will be the ability to form strategic alliances with some of its suppliers. In the past, the fact that many suppliers used by IBM for its production processes were as far as 12,000 miles away made it difficult to build strategic alliances with them. IBM believes that using the Internet will strengthen relations and enable it to develop alliances.

"The Internet also will play an important role in IBM's general procurement . . . IBM was doing EDI with core production suppliers, but not with . . . other forms of general procurement. Purchasers were still faxing and phoning orders, which is timely and costly."

Additional cost savings come from small volume, one-of-a-kind special purchases, because of the speed and ease of using the Internet.

Web-based procurement will eliminate mistakes that occur during the procurement process due to having to type or enter prices and other figures on paper documents.

Questions

1. How did IBM achieve cost reductions by using the Internet for procurement?
2. What advantage did IBM's use of the Internet have for small suppliers?
3. Aside from cost reduction, what major value does IBM envision for its interaction with suppliers?
4. How does use of the Internet for procurement reduce mistakes? Indicate how using the Internet made that benefit possible.
5. How does having a web-based portal help IBM's suppliers?

Source: Based on James Carbone, "E-Procurement at IBM: POs Are Just the Beginning," *Purchasing* 128, no. 4 (March 23, 2000), p. S50.

Requirements for a Successful Supply Chain

Successful supply chain management requires trust among trading partners, effective communication, supply chain visibility, event management capability, and performance metrics.

Trust. It is essential for major trading partners to trust each other, and feel confident that partners share similar goals and that they will take actions that are mutually beneficial.

Effective communication. Effective supply chain communication requires integrated technology and standardized ways and means of communicating among partners.

Supply chain visibility. **Supply chain visibility** means that a major trading partner can connect to any part of its supply chain to access data in real time on inventory levels, shipment status, and similar key information. This requires data sharing.

supply chain visibility A major trading partner can connect to its supply chain to access data in real time.

Event management capability. **Event management** is the ability to detect and respond to unplanned events such as delayed shipment, or a warehouse running low on a certain item. An event management system should have four capabilities: *monitoring* the system, *notifying* when certain planned or unplanned events occur, *simulating* potential solutions when an unplanned event occurs, and *measuring* the long-term performance of suppliers, transporters, and other supply chain partners in the supply chain.

event management The ability to detect and respond to unplanned events.

Performance metrics. Performance metrics are necessary to confirm that the supply chain is functioning as expected, or that there are problems that must be addressed. There are a variety of measures that can be used, that relate to such things as late deliveries, inventory turnover, response time, quality issues, and so on. In the retail sector, the **fill rate** (the percentage of demand filled from stock on hand) is often very important.

fill rate The percentage of demand filled from stock on hand.

Another approach is to use the Supply Chain Operations Reference (SCOR) model, a portion of which is presented in Table 16.4. The SCOR model reflects an effort to standardize measurement of supply chain performance.

Successful supply chain management requires integration of all aspects of the supply chain: suppliers, warehouses, factories, distributors, and retail outlets. This requires cooperation

TABLE 16.4
SCOR (Supply Chain Operations Reference model) metrics

Perspective	Metrics
Reliability	On-time delivery
	Order fulfillment lead time
	Fill rate (fraction of demand met from stock)
	Perfect order fulfillment
Flexibility	Supply chain response time
	Upside production flexibility
Expenses	Supply chain management cost
	Warranty cost as a percentage of revenue
	Value added per employee
Assets/utilization	Total inventory days of supply
	Cash-to-cash cycle time
	Net asset turns

Source: Based on information available at www.supply-chain.org by the Supply Chain Council.

among supply chain partners in planning, coordination of activities, and information sharing, which, in turn, requires partners to agree on common goals (goal sharing). This requires trust and a willingness to cooperate to achieve the common goals. Coordination and information sharing are critical to the effective operation of a supply chain.

Information exchange must be reciprocal: Partners share forecasts and sales data, as well as information on inventory quantities, impending shortages, breakdowns, delays, and other problems that could impact the timely flow of products and services through the chain. Information has a time value, and the longer it takes to disseminate information once it materializes, the lower its value. Thus, instead of each organization in a supply chain making plans based on a combination of actual orders plus forecasts of demand of its immediate customer, by sharing data on end-customer sales and partner inventory on a real-time basis, each organization in the chain can develop plans that contribute to synchronization across the chain. Collaborative Planning, Forecasting, and Replenishment is a recent step in that direction.

CPFR A supply chain initiative that focuses on information sharing among supply chain trading partners in planning, forecasting, and inventory replenishment.

CPFR **CPFR (Collaborative Planning, Forecasting, and Replenishment)** is a fairly new supply chain initiative that focuses on information sharing among supply chain trading partners for purposes of planning, forecasting, and inventory replenishment. CPFR begins with an agreement between major partners to develop a joint market plan, with both (all) partners agreeing to own the process and the plan. The plan outlines what is going to be sold, how it will be promoted, and the time frame in which it will be sold. A partner is allowed to make certain changes to the plan within agreed upon parameters. Other changes require approval of the other partner(s), and may require negotiations. The plan is a key input to the forecast.

CPFR systems incorporate key information such as promotion timing and supply constraints that can effectively eliminate a significant amount of inventory from the supply chain. Under CPFR, a forecast can be frozen, and can then be converted into a shipping plan, eliminating the typical order processing.

CPFR

READING

Collaborative Planning, Forecasting and Replenishment (CPFR), a set of guidelines supported and published by the VICS Association, changes the rules, so companies throughout the supply chain can simultaneously lower costs and improve customer service. Trading partners share their plans for future events, and then use an exception-based process to deal with changes or deviations from plans. By working on issues before they occur, both partners have time to react. A supplier can build inventory well in advance of receiving a promotional order and carry less

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safety stock at other times. A retailer can alter the product mix to reduce the impact of supply problems. In short, both sides win, and the consumer ultimately benefits from lower prices.

The CPFR process is divided into nine steps:

Step 1—Front-end agreement: Participating companies identify executive sponsors, agree to confidentiality and dispute resolution processes, develop a scorecard to track key supply chain metrics relative to success criteria, and establish any financial incentives or penalties.

Step 2—Joint business plan: The project teams develop plans for promotions, inventory policy changes, store openings/closings, and product changes for each product category.

Steps 3–5—Sales forecast collaboration: Trading partners share consumer demand forecasts, and identify exceptions that occur when partners' plans do not match, or change dramatically. They resolve exceptions by determining causal factors, adjusting plans where necessary.

Steps 6–8—Order forecast collaboration: Trading partners share replenishment plans, identifying and resolving exceptions.

Step 9—Order generation/delivery execution: Results data (POS, orders, shipments, on-hand inventory) is shared, and forecast accuracy problems, overstock/understock conditions, and execution issues are identified and resolved.

Step 1 ensures that each company has an adequate commitment to collaboration, and that all parties are aligned around common goals. This front-end agreement might be reviewed on an annual basis. Step 2 applies good category management principles—borrowed from the Efficient Consumer Response (ECR) initiative—to create a joint plan for going to market. This would typically be revised quarterly, or semi-annually. What makes CPFR unique is that this joint business plan is used to control the day-to-day activities of manufacturing, delivering, and selling products. That's where Steps 3–9 come in.

A core assumption of CPFR is that each organization will enter the details of the joint business plans into their on-line planning systems, and then share the results on a regular basis as market conditions change and logistical problems occur. Because each company may manage thousands of products distributed across thousands of locations, it is not feasible for planners to compare these plans manually and determine which changes are significant. Instead, a specialized CPFR system exchanges and compares each value using thresholds that planners have set. If changes in one plan, or differences between them exceed the threshold, the CPFR system alerts the planner to the problem. Forecast revisions are exchanged on a regular—usually weekly—basis.

The CPFR philosophy is that if plans are "close enough", they probably do not require attention. Even when trading partners have identical objectives, differences in statistical forecasting or constraint-based planning algorithms will produce minor variances in plans. These are not significant relative to statistical deviations in demand, and safety stock will take care of them. CPFR technology is essential to identifying exceptions, because of the millions of product/location combinations that are planned, and because of the unique perspectives (product, location, and partner hierarchies) of each supply chain participant.

CPFR Results

Only a few CPFR initiatives have published the results of their collaboration, but these have been eye-opening. Nabisco and **Wegmans,** for example, noted over a 50% increase in category sales. Wal-Mart and Sara Lee reported a 14% reduction in store-level inventory with a 32% increase in sales. Kimberly-Clark and Kmart achieved steady increases in category sales growth that exceeded market growth.

It may be surprising to see such dramatic sales increases linked to a "supply chain" initiative like CPFR. While improved in-stock levels can increase sales, they wouldn't normally be responsible for a 50% lift. Joint business planning (CPFR step 2) was behind most of these increases in the pilot projects. These increases are clearly not sustainable when CPFR is applied across the board; more telling is that in spite of the sudden sales increase, inventory did not increase in the Nabisco-Wegmans pilot, leading to higher inventory turns. Steps 3 through 9 of CPFR can take credit for keeping inventory under control in the face of sharply higher sales.

CPFR Process Synchronizes Planning

From a business process standpoint, CPFR defines how trading partners can synchronize their different planning functions. Retailers are focused on predicting consumer reaction to promotions, competitors, and product category changes, while suppliers usually concentrate on managing the level of inventory at distribution centers. The retailer's objective is to keep products in stock in stores. The supplier's objective is to create the most efficient production and replenishment process possible. These differences are reflected in each party's sales and order forecasting processes.

Sales (Consumer Demand) Forecast Comparisons

Retailers produce very detailed sales forecasts, often including weekly (or even daily) store-level demand per SKU. Suppliers may also gather a great deal of intelligence about what sold from a syndicated data source (typically IRI or Nielsen), but they usually create only market- or account-level forecasts. The CPFR solution aggregates the detailed sales forecasts from trading partner and compares the total.

Order Forecast (Replenishment Plan) Comparisons

Often, retailers do not produce an order forecast at all. When retailers do produce an order forecast, it may include only base demand. Many handle promotional orders through a totally different process, tools, and personnel. Suppliers, therefore, don't often get an integrated view of the retailer's demand. A CPFR solution can improve this situation by providing a forum where replenishment order forecasts and promotional orders can be brought together and compared in full.

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CPFR Technology Fits Existing Applications

Putting CPFR technology into action requires sophisticated data processing and network technology. CPFR systems stand on their own, but must interact with existing supply and demand chain applications in an enterprise. The points of contact depend upon whether a company is a retailer or supplier.

The CPFR solution collects planning and historical data from retail systems, identifies exceptions, and forwards relevant data to suppliers for review and processing. On the supplier side, a different set of applications contributes to the CPFR process. *Customer relationship management (CRM)* applications help the sales force develop promotions and sales forecasts. *Advanced planning and scheduling (APS)* applications create optimal replenishment plans. *Enterprise resource planning (ERP)* applications produce and distribute products, based upon firm demand.

The CPFR system compares the data it collects from the supplier's enterprise systems with the data it receives from retail partners. It generates any exceptions it finds and communicates results with the retailer's CPFR solution.

The CPFR solution itself does not have to be deployed at each trading partner. Instead, several companies offer hosting services that run CPFR solutions for a trading community. The cost to participants will be substantially less than if individual participants were to develop their own systems.

Companies only need access to the Internet. Data is uploaded to the hosting service through a secure connection. Then planners access their company's view through a web browser. Participants who use a single, public exchange achieve exchange-to-exchange interoperability and end-to-end visibility across the supply chain.

Companies that subscribe to single, public marketplaces such as Transora, reap another technological benefit. Participants will not need to manage the technology platform and can spend their time fortifying supplier and retailer relationships, making work process more efficient, and developing key competitive strategies with the data generated.

Conclusion

CPFR is rapidly becoming mainstream. One retailer already has 20 partners online, with announced plans for 200. Other industries, as exemplified by the RosettaNet high tech consortium, have adopted CPFR business practices as well. Innovative manufacturers are also beginning to do forecast collaboration with their own suppliers—resulting in end-to-end collaboration. Barriers to participation are low, and benefits are being demonstrated.

Source: Excerpted from "An Introduction to the CPFR." © 2001 Syncra Systems, Inc. Guidelines as published by *the VICS Association*. Collaborative Planning, Forecasting and Replenishment is a registered trademark of the Voluntary Interindustry Commerce Standards (VICS) Association.

Steps in Creating an Effective Supply Chain

Creation of an effective supply chain entails several key steps:

1. Develop strategic objectives and tactics. These will guide the process.
2. Integrate and coordinate activities in the internal portion of the chain. This requires (1) overcoming barriers caused by functional thinking that lead to attempts to optimize a subset of a system rather than the system as a whole and (2) transferring data and coordinating activities.
3. Coordinate activities with suppliers and with customers. This involves addressing supply and demand issues.
4. Coordinate planning and execution across the supply chain. This requires a system for transferring data across the supply chain and allowing access to data to those who engage in operations to which it will be useful.
5. Consider the possibilities of forming *strategic partnerships*. **Strategic partnering** occurs when two or more business organizations that have complementary products or services that would *strategically* benefit the others agree to join so that each may realize a strategic benefit. One way this occurs is when a supplier agrees to hold inventory for a customer, thereby reducing the customer's cost of holding the inventory, in exchange for the customer agreeing to a long-term commitment, thereby relieving the supplier of the costs that would be needed to continually find new customers, negotiate prices and services, and so on.

strategic partnering Two or more business organizations that have complementary products or services join so that each may realize a strategic benefit.

NestléUSA and Ocean Spray Form Strategic Operations Alliance

NEWSCLIP

Glendale, CA—01/25/02—The NestléUSA—Beverage Division and Ocean Spray Cranberries, Inc., announced today that they have formed a long-term strategic operations alliance that will enable both companies to significantly increase manufacturing and supply chain efficiency, while maintaining high quality products for their respective juice businesses.

"Ocean Spray shares many of our same business values, in particular their commitment to high quality manufacturing standards," said Mike Mitchell, President and General Manager of NestléUSA—Beverage Division. "By capitalizing upon each other's best practices, we feel both Nestlé and Ocean Spray will be better equipped to grow in this highly aggressive juice category in which we compete."

Within the strategic operations alliance, Nestlé will transition over time its manufacturing of Libby's Juicy Juice and Libby's Kerns Nectars to Ocean Spray facilities. The companies will also pursue collaborative procurement of common raw and packaging materials, and common operating supplies, as well as shared logistics to increase process efficiency across the supply chain.

"This alliance between two great companies creates a powerful synergy," said Ocean Spray President and Chief Operating Officer Randy Papadellis. "By bringing Nestlé juice production into our plants and joining forces with them on purchasing and distribution, we will establish an economy of scale that will boost the profitability of both companies."

With Ocean Spray leading the category of shelf stable juices and Libby's Juicy Juice being the leader in 100% juice for kids, the operations alliance is expected to create added value of mutual benefit. The strategic operations alliance will be governed by a leadership team and an executive operating committee, both comprised of members from each company.

Source: www.Nestleusa.com, www.NestleNewsroom.com.

In many cases, organizations have accomplished much of what is required to achieve the second and third steps in the process; it is the first and last steps that will require attention. In all steps, designers must address the following performance drivers:

1. Quality
2. Cost
3. Flexibility
4. Velocity
5. Customer service

Quality, cost, and customer service are perhaps obvious. Flexibility refers to the ability to adjust to changes in order quantities but also to the ability to adjust to changes in product or service requirements. Velocity refers to the rate or speed of travel through the system. Velocity is important in two areas: materials and information. **Inventory velocity** refers to the rate at which inventory (material) goes through the system. Faster is better: The quicker materials pass through the supply chain, the lower inventory costs will be, and the quicker products and services will be delivered to the customer, and turned into cash. **Information velocity** refers to the speed at which information is transferred within a supply chain. Again, faster is better: The quicker information (two-way flow) is available to decision makers, the better their decisions will be in planning and coordinating their parts of the supply chain.

inventory velocity The rate at which inventory (material) goes through the supply chain.

information velocity The rate at which information is communicated in a supply chain.

Using Information to Speed Execution

READING

Kevin Rollins

www.dell.com

Most of the managerial challenges at Dell Computer have to do with what we call *velocity*—speeding the pace of every element of our business. Life cycles in our business are measured in months, not years, and if you don't move fast, you're out of the game. Managing velocity is about managing information—using a constant flow of information to drive operating practices, from the performance measures we track to how we work with our suppliers.

Performance Metrics

At Dell, we use the balance sheet and the fundamentals of the P&L on a monthly basis as tools to manage operations. From the balance sheet, we track three cash-flow measures very closely. We look at weekly updates of how many days of inventory we have, broken out by product component. We can then work closely with our suppliers so we end up with the right inventory. When it's not quite right, we can use our direct-sales model to steer customers toward comparable products that we do have. So we use inventory information to work both the front and back ends at the same time.

We also track and manage receivables and payables very tightly. This is basic blocking and tackling, but we give it a high priority. The payoff is that we have a negative cash-conversion cycle of five days—that is, we get paid before we have to pay our suppliers. Since our competitors usually have to support their resellers by offering them credit, the direct model gives us an inherent cost advantage. And the more we can shorten our cash-collection cycle, the greater our advantage.

The real-time performance measures in the P&L that we regard as the best indicators of the company's health are our margins, our average selling price, and the overhead associated with selling. We split the P&L into these core elements by customer segment, by product, and by country. These metrics can alert us instantly to problems, for example, with the mix of products being sold in any particular country.

Working with Suppliers

The greatest challenge in working with suppliers is getting them in sync with the fast pace we have to maintain. The key to making it work is information. The right information flows allow us to work with our partners in ways that enhance speed, either directly by improving logistics or indirectly by improving quality.

Take our service strategy, for example. Customers pay us for service and support, and we contract with third-party maintainers (TPMs) to make the service calls. Customers call us when they have problems, and that initial call will trigger two electronic dispatches—one to ship the needed parts directly from Dell to the customers' sites and one to dispatch the TPMs to the customers. Our role as information broker facilitates the TPMs' work by making sure the necessary parts will be on-site when they arrive.

But our role doesn't stop there. Because poor quality creates friction in the system, which slows us down, we want to capture information that can be used to fix problems so they won't happen again. So we take back the bad part to diagnose what went wrong, and we feed that information back to our suppliers so they can redesign the component. Clearly, we couldn't operate that way if we were dealing with hundreds of suppliers. So for us, working with a handful of partners is one of the keys to improving quality—and therefore speed—in our system.

Kevin Rollins is vice chairman of Dell Computer Corporation.

Source: Reprinted by permission of *Harvard Business Review*, from "The Power of Virtual Integration: An Interview with Dell" by Kevin Rollins, March/April 1998, p. 81.

Optimizing the Supply Chain

Optimizing the supply chain means maximizing shareholder and customer value. This is achieved by fully integrating all members of the supply chain, collaboratively balancing resources of chain members, and optimizing the flow of goods, services, and information from source to end customer. To do this, it is necessary to maximize the velocity of information transfer and minimize response time.

Challenges

Barriers to Integration of Separate Organizations Organizations, and their functional areas, have traditionally had an inward focus. They set up buffers between themselves and their suppliers. Changing that attitude can be difficult. The objective of supply chain management is to be efficient across the entire supply chain.

One difficulty in achieving this objective is that different components of the supply chain often have conflicting objectives. For example, to reduce their inventory holding costs, some companies opt for frequent small deliveries of supplies. This can result in increased holding costs for suppliers, so the cost is merely transferred to suppliers. Similarly, within an organization, functional areas often make decisions with a narrow focus, doing things that "optimize" results under their control; in so doing, however, they may suboptimize results for the overall organization. To be effective, organizations must adopt a *systems approach* to both the internal and external portions of their supply chains, being careful to make decisions that are consistent with optimizing the supply chain.

Another difficulty is that for supply chain management to be successful, organizations in the chain must allow other organizations access to their data. There is a natural reluctance to do this in many cases. One reason can be lack of trust; another can be unwillingness to share proprietary information in general; and another can be that an organization, as a member of multiple chains, fears exposure of proprietary information to competitors.

Getting CEOs, Boards of Directors, Managers, and Employees "Onboard" CEOs and boards of directors need to be convinced of the potential payoffs from supply chain management. And because much of supply chain management involves a change in the way business has been practiced for an extended period of time, getting managers and workers to adopt new attitudes and practices that are consistent with effective supply chain operations poses a real challenge.

Dealing with Trade-offs Authors Hau Lee and C. Billington list a number of trade-offs that must be taken into account in structuring a supply chain[2]:

1. *Lot size–inventory trade-off.* Producing or ordering large lot sizes yields benefits in terms of quantity discounts and lower annual setup costs, but it increases the amount of safety stock carried by suppliers and, hence, the carrying cost. It also can create the *bullwhip effect.*

It is caused by the way inventories are replenished at various points along a supply chain. For a variety of reasons, organizations tend to periodically order batches of an item from their suppliers. This creates "lumpy" demand for suppliers and, hence, high-variability demand, which causes suppliers to carry relatively large amounts of safety stock. Starting with the final customer and moving backward through the supply chain, batch sizes tend to increase, thereby increasing the level of safety stock carried. What is so striking about this phenomenon is that any demand variations that exist at the customer end of the supply chain get magnified as orders are generated back through the supply chain.

2. *Inventory–transportation cost trade-off.* Suppliers prefer to ship full truckloads instead of partial loads in order to spread shipping costs over as many units as possible. This leads to higher holding costs for customers. Solutions include combining orders to realize full truckloads, downsizing truck capacity, and shipping late in the process along with *cross-docking.* **Cross-docking** is a technique whereby goods arriving at a warehouse from a supplier are unloaded from the supplier's truck and immediately loaded on one or more outbound trucks, thereby avoiding storage at the warehouse completely. Wal-Mart is among the companies that have used this technique successfully to reduce inventory holding costs and lead times.

cross-docking Goods arriving at a warehouse from a supplier are unloaded from the supplier's truck and loaded onto outbound trucks, thereby avoiding warehouse storage.

3. *Lead time–transportation cost trade-off.* Suppliers usually prefer to ship in full loads, as mentioned previously. But waiting for sufficient orders and/or production to achieve a full load increases lead time. In addition to the preceding suggestions, improved forecasting information to suppliers might improve the timing of their production and orders to their suppliers.

4. *Product variety–inventory trade-off.* Higher product variety generally means smaller lot sizes, which results in higher setup costs, as well as higher transportation and inventory management costs. One possible means of reducing some costs is **delayed differentiation,** which means producing standard components and subassemblies, then waiting until late in the process to add differentiating features. For example, an automobile producer may produce and

delayed differentiation Production of standard components and subassemblies, which are held until late in the process to add differentiating features.

[2]Hau L. Lee and C. Billington, "Managing Supply Chain Inventory: Pitfalls and Opportunities," *Sloan Management Review,* Spring 1992, pp. 65–73.

ship cars without radios, allowing customers to select from a range of radios that can be installed by the dealer, thereby eliminating that variety from much of the supply chain.

5. *Cost–customer service trade-off.* Producing and shipping in large lots reduces costs, but it increases lead times, as previously noted. One approach to reducing lead time is to ship directly from a warehouse to the customer, bypassing a retail outlet. Reducing one or more steps in a supply chain by cutting out one or more intermediaries is referred to as **disintermediation**. Although transportation costs are higher, storage costs are lower.

disintermediation Reducing one or more steps in a supply chain by cutting out one or more intermediaries.

Small Businesses Small businesses may be reluctant to embrace supply chain management because it can involve specialized, complicated software as well as sharing sensitive information with outside companies. Nonetheless, in order for them to survive, they may have to do so.

Variability and Uncertainty Variations create uncertainty, thereby causing inefficiencies in a supply chain. Variations occur in incoming shipments from suppliers, internal operations, deliveries of products or services to customers, and customer demands. Increases in product and service *variety* add to uncertainty, because organizations have to deal with a broader range and frequent changes in operations. Hence, when deciding to increase variety, organizations should consider this trade-off.

Although variations exist throughout most supply chains, decision makers often treat the uncertainties as if they were certainties and make decisions on that basis. In fact, systems are often designed on the basis of certainty, so they may not be able to cope with uncertainty. Unfortunately, uncertainties are detrimental to scheduling, leading to various undesirable occurrences, including inventory buildups, bottleneck delays, missed delivery dates, and frustration for employees and customers at all stages of a supply chain.

Response Time Response time is an important issue in supply chain management. Long lead times impair the ability of a supply chain to quickly respond to changing conditions, such as changes in the quantity or timing of demand, changes in product or service design, and quality or logistics problems. Therefore, it is important to work to reduce long product lead times and long collaborative lead times, and a plan should be in place to deal with problems when they arise.

Table 16.5 lists some potential solutions to supply chain problems and possible drawbacks.

TABLE 16.5
Benefits and possible drawbacks of potential improvements to a supply chain

Problem	Potential Improvement	Benefits	Possible Drawbacks
Large inventories	Smaller, more frequent deliveries, cross-docking	Reduced holdings costs	Traffic congestion, increased ordering costs, increased supplier costs
Long lead times	Delayed differentiation Disintermediation	Quick response Quick response	May not be feasible May need to absorb functions
Large number of parts	Modular construction	Fewer parts to keep track of, simpler ordering	Less variety
Cost, quality	Outsourcing	Reduced cost, higher quality, fewer internal problems, remaining operations more focused	Loss of control
Variability	Shorter lead times, better forecasts, reduction in product/service variety	Better able to match supply and demand	Less variety

Purchasing is "critical to supply chain efficiency because it is the job of purchasing to select suppliers and then establish mutually beneficial relationships with them. Without good suppliers and without superior purchasing, supply chains cannot compete in today's" marketplace. Purchasing is also very involved in product design and development work. Many "manufacturers have found out that manufacturing costs can be reduced, product quality maximized, and new products brought to market at a much faster rate if purchasing brings key suppliers into the product design and development at the earliest stage of the process." And purchasing is directly involved in the implementation of e-commerce systems.

Source: Based on Kevin R. Fitzgerald, "Purchasing Occupies Key Position in Supply Chains," *Supply Chain Yearbook 2000* (New York: Cahners Business Information, 2000), p. 21.

PURCHASING

Purchasing is responsible for obtaining the materials, parts, supplies, and services needed to produce a product or provide a service. You can get some idea of the importance of purchasing when you consider that, in manufacturing, upwards of 60 percent of the cost of finished goods comes from purchased parts and materials. Furthermore, the percentages for purchased inventories are even higher for retail and wholesale companies, sometimes exceeding 90 percent. Nonetheless, the importance of purchasing is more than just the cost of goods purchased; other important factors include the *quality* of goods and services and the *timing* of deliveries of goods or services, both of which can have a significant impact on operations.

The goal of purchasing is to develop and implement purchasing plans for products and services that support operations strategies. Among the duties of purchasing are identifying sources of supply, negotiating contracts, maintaining a database of suppliers, obtaining goods and services that meet or exceed operations requirements in a timely and cost-efficient manner, and managing suppliers. Thus, purchasing selects suppliers, negotiates contracts, establishes alliances, and acts as liaison between suppliers and various internal departments.

Purchasing is taking on increased importance as organizations place greater emphasis on supply chain management, quality improvement, lean production, and outsourcing. Moreover, business-to-business buying relationships are changing: Although traditional relationships currently account for the lion's share of buying relationships, they are expected to decrease substantially by the middle of the decade, while web-based auctions and managed inventory relationships are expected to grow. In addition, increasing globalization will continue to have an impact on purchasing.

Purchasing Interfaces

Purchasing has interfaces with a number of other functional areas, as well as with outside suppliers. Purchasing is the connecting link between the organization and its suppliers. In this capacity, it exchanges information with suppliers and functional areas. The interactions between purchasing and these other areas are briefly summarized in the following paragraphs.

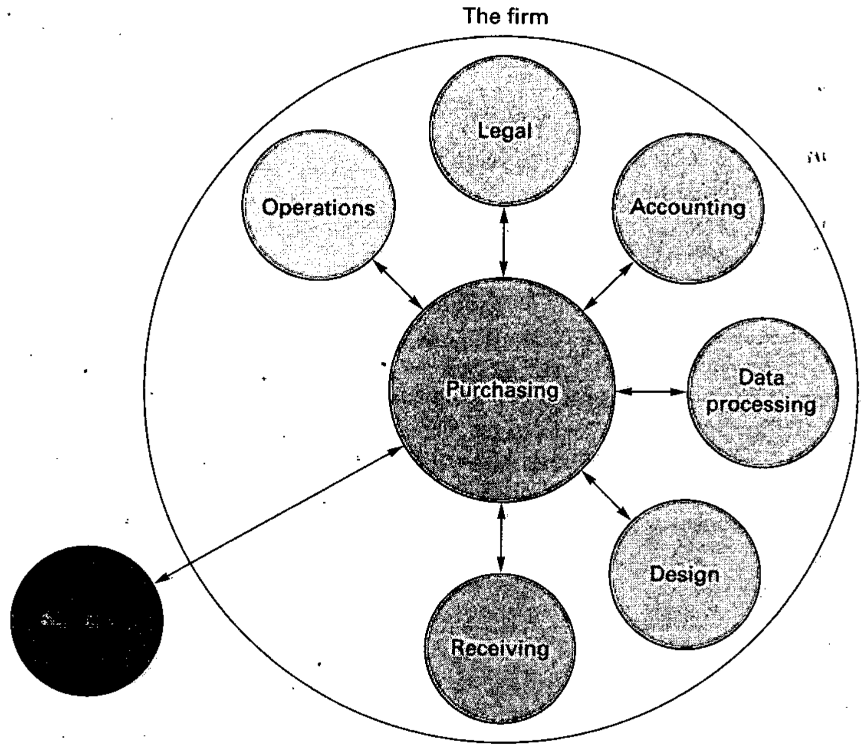
Operations constitute the main source of requests for purchased materials, and close cooperation between these units and the purchasing department is vital if quality, quantity, and delivery goals are to be met. Cancellations, changes in specifications, or changes in quantity or delivery times must be communicated immediately for purchasing to be effective.

The purchasing department may require the assistance of the *legal* department in contract negotiations, in drawing up bid specifications for nonroutine purchases, and in helping interpret legislation on pricing, product liability, and contracts with suppliers.

Accounting is responsible for handling payments to suppliers and must be notified promptly when goods are received in order to take advantage of possible discounts. In many firms, *data processing* is handled by the accounting department, which keeps inventory records, checks invoices, and monitors vendor performance.

Design and *engineering* usually prepare material specifications, which must be communicated to purchasing. Because of its contacts with suppliers, purchasing is often in a position to pass information about new products and materials improvements on to design personnel. Also, design and purchasing people may work closely to determine whether changes in specifications, design, or materials can reduce the cost of purchased items (see the following section on value analysis).

FIGURE 16.5
Purchasing interfaces



Receiving checks incoming shipments of purchased items to determine whether quality, quantity, and timing objectives have been met, and it moves the goods to temporary storage. Purchasing must be notified when shipments are late; accounting must be notified when shipments are received so that payments can be made; and both purchasing and accounting must be apprised of current information on continuing vendor evaluation.

Suppliers or vendors work closely with purchasing to learn what materials will be purchased and what kinds of specifications will be required in terms of quality, quantity, and deliveries. Purchasing must rate vendors on cost, reliability, and so on (see the later section on vendor analysis). Good supplier relations can be important on rush orders and changes, and vendors provide a good source of information on product and material improvements.

Figure 16.5 depicts the purchasing interfaces.

The Purchasing Cycle

purchasing cycle Series of steps that begin with a request for purchase and end with notification of shipment received in satisfactory condition.

The **purchasing cycle** begins with a request from within the organization to purchase material, equipment, supplies, or other items from outside the organization, and the cycle ends when the purchasing department is notified that a shipment has been received in satisfactory condition. The main steps in the cycle are these:

1. *Purchasing receives the requisition.* The requisition includes (*a*) a description of the item or material desired, (*b*) the quantity and quality necessary, (*c*) desired delivery dates, and (*d*) who is requesting the purchase.
2. *Purchasing selects a supplier.* The purchasing department must identify suppliers who have the capability of supplying the desired goods. If no suppliers are currently listed in the files, new ones must be sought. Vendor ratings may be referred to in choosing among vendors, or perhaps rating information can be relayed to the vendor with the thought of upgrading future performance.
3. *Purchasing places the order with a vendor.* If the order involves a large expenditure, particularly for a one-time purchase of equipment, for example, vendors will usually be asked to bid on the job, and operating and design personnel may be asked to assist in negotiations with a vendor. Large-volume, continuous-usage items may be covered by blanket purchase orders, which often involve annual negotiation of prices with deliveries subject to request

throughout the year. Moderate-volume items may also have blanket purchase orders, or they may be handled on an individual basis. Small purchases may be handled directly between the operating unit requesting a purchased item and the supplier, although some control should be exercised over those purchases so they don't get out of hand.

4. *Monitoring orders.* Routine follow-up on orders, especially large orders or those with lengthy lead times, allows the purchasing department to project potential delays and relay that information to the operating units. Conversely, the purchasing department must communicate changes in quantities and delivery needs of the operating units to suppliers to allow them time to change their plans.
5. *Receiving orders.* Receiving must check incoming shipments for quality and quantity. It must notify purchasing, accounting, and the operating unit that requested the goods. If the goods are not satisfactory, they may have to be returned to the supplier or subjected to further inspection.

Value Analysis

Value analysis refers to an examination of the *function* of purchased parts and materials in an effort to reduce the cost and/or improve the performance of those items. Typical questions that would be asked as part of the analysis include: Could a cheaper part or material be used? Is the function necessary? Can the function of two or more parts or components be performed by a single part for a lower cost? Can a part be simplified? Could product specifications be relaxed, and would this result in a lower price? Could standard parts be substituted for nonstandard parts? Table 16.6 provides a checklist of questions that can guide a value analysis.

value analysis Examination of the function of purchased parts and materials in an effort to reduce cost and/or improve performance.

TABLE 16.6
Overview of value analysis

1. Select an item that has a high annual dollar volume. This can be material, a purchased item, or a service.
2. Identify the function of the item.
3. Obtain answers to these kinds of questions:
   a. Is the item necessary; does it have value; can it be eliminated?
   b. Are there alternative sources for the item?
   c. Can the item be provided internally?
   d. What are the advantages of the present arrangement?
   e. What are the disadvantages of the present arrangement?
   f. Could another material, part, or service be used instead?
   g. Can specifications be less stringent to save cost or time?
   h. Can two or more parts be combined?
   i. Can more/less processing be done on the item to save cost or time?
   j. Do suppliers/providers have suggestions for improvements?
   k. Do employees have suggestions for improvements?
   l. Can packaging be improved or made less costly?
4. Analyze the answers obtained as well as answers to other questions that arise, and make recommendations.

Naturally, purchasing cannot perform an investigation each time materials are ordered. However, it should conduct value analysis periodically on large dollar-volume items because of the potential savings.

Although purchasing does not ordinarily have the authority to implement changes on the basis of a value analysis, it can make suggestions to operating units, designers, and suppliers, which may lead to improved performance of purchased goods and/or reduction of the cost of those goods. Purchasing can offer a different perspective to the analysis, and purchasing people, because of their association with suppliers, possess information not known to others within the organization. If a fair amount of technical knowledge is required to review a part or service, a team can be formed with representatives from design and operations to work with purchasing to conduct the analysis.

Centralized versus Decentralized Purchasing

Purchasing can be centralized or decentralized. Centralized purchasing means that purchasing is handled by one special department. Decentralized purchasing means that individual departments or separate locations handle their own purchasing requirements.

centralized purchasing Purchasing is handled by one special department.

Centralized purchasing may be able to obtain lower prices than decentralized units if the higher volume created by combining orders enables it to take advantage of quantity discounts offered on large orders. Centralized purchasing may also be able to obtain better service and closer attention from suppliers. In addition, centralized purchasing often enables companies to assign certain categories of items to specialists, who tend to be more efficient because they are able to concentrate their efforts on relatively few items instead of spreading themselves across many items.

decentralized purchasing Individual departments or separate locations handle their own purchasing requirements.

Decentralized purchasing has the advantage of awareness of differing "local" needs and being better able to respond to those needs. Decentralized purchasing usually can offer quicker response than centralized purchasing. Where locations are widely scattered, decentralized purchasing may be able to save on transportation costs by buying locally, which has the added attraction of creating goodwill in the community.

Some organizations manage to take advantage of both centralization and decentralization by permitting individual units to handle certain items while centralizing purchases of other items. For example, small orders and rush orders may be handled locally or by departments, while centralized purchases would be used for high-volume, high-value items for which discounts are applicable or specialists can provide better service than local buyers or departments.

Ethics in Purchasing

Ethical behavior is important in all aspects of business. This is certainly true in purchasing, where the temptations for unethical behavior can be enormous. Buyers often hold great power, and salespeople are often eager to make a sale. Unless both parties act in an ethical manner, the potential for abuse is very real. Furthermore, with increased globalization, the challenges are particularly great because a behavior regarded as customary in one country might be regarded as unethical in another country.

TABLE 16.7
Guidelines for ethical behavior in purchasing

Principles

1. Loyalty to employer.
2. Justice to those you deal with.
3. Faith in your profession.

Standards of purchasing practice

1. Avoid appearance of unethical or compromising practice.
2. Follow the lawful instructions of your employer.
3. Refrain from private activity that might conflict with the interests of your employer.
4. Refrain from soliciting or accepting gifts, favors, or services from present or potential suppliers.
5. Handle confidential or proprietary employer or supplier information with due care.
6. Practice courtesy and impartiality in all aspects of your job.
7. Refrain from reciprocal agreements that constrain competition.
8. Know and obey the letter and spirit of laws governing purchasing.
9. Demonstrate support for small, disadvantaged, and minority-owned businesses.
10. Discourage involvement in employer-sponsored programs of nonbusiness, personal purchases.
11. Enhance the profession by maintaining current knowledge and the highest ethical standards.
12. Conduct international purchasing in accordance with the laws, customs, and practices of foreign countries, but consistent with the laws of the United States, your organization's policies, and these guidelines.

Source: Reprinted with permission from the publishers, The Institute for Supply Management™, *Principles and Standards of Ethical Supply Management Conduct*, approved January 2002. ISM's Ethical Standards Committee developed these guidelines in order to heighten awareness and acceptance of appropriate conduct. They are intended to be a model set of guidelines and not to supplant any company policies.

The National Association of Purchasing Management has established a set of guidelines for ethical behavior. (See Table 16.7.) As you read through the list, you get insight into the scope of ethics issues in purchasing.

SUPPLIER MANAGEMENT

Reliable and trustworthy suppliers are a vital link in an effective supply chain. Timely deliveries of goods or services and high quality are just two of the ways that suppliers can contribute to effective operations. A purchasing manager may function as an "external operations manager," working with suppliers to coordinate supplier operations and buyer needs.

In this section, various aspects of supplier management are described, including supplier audits, supplier certification, and supplier partnering. The section starts with an aspect that can have important ramifications for the entire organization: choosing suppliers.

Choosing Suppliers

In many respects, choosing a vendor involves taking into account many of the same factors associated with making a major purchase (e.g., a car or stereo system). A company considers price, quality, the supplier's reputation, past experience with the supplier, and service after the sale. The main difference is that a company, because of the quantities it orders and operations requirements, often provides suppliers with detailed specifications of the materials or parts it wants instead of buying items off the shelf, although most organizations buy standard items that way. The main factors a company takes into account when it selects a vendor are outlined in Table 16.8.

Because different factors are important for different situations, purchasing must decide, with the help of operations, the importance of each factor (i.e., how much weight to give to each factor), and then rate potential vendors according to how well they can be expected to perform against this list. This process is called **vendor analysis**, and it is conducted periodically, or whenever there is a significant change in the weighting assigned to the various factors.

vendor analysis Evaluating the sources of supply in terms of price, quality, reputation, and service.

Supplier Audits

Periodic audits of suppliers are a means of keeping current on suppliers' production (or service) capabilities, quality and delivery problems and resolutions, and suppliers' performance

TABLE 16.8
Choosing a supplier

Factor	Typical Questions
Quality and quality assurance	What procedures does the supplier have for quality control and quality assurance? Are quality problems and corrective actions documented?
Flexibility	How flexible is the supplier in handling changes in delivery schedules, quantity, and product or service changes?
Location	Is the supplier nearby?
Price	Are prices reasonable given the entire package the supplier will provide? Is the supplier willing to negotiate prices? Is the supplier willing to cooperate to reduce costs?
Product or service changes	How much advance notification does the supplier require for product or service changes?
Reputation and financial stability	What is the reputation of the supplier? How financially stable is the supplier?
Flexibility	How flexible is the supplier in handling changes in delivery schedules, quantity, and product or service changes?
Lead times and on-time delivery	What lead times can the supplier provide? What procedures does the supplier have for assuring on-time deliveries? What procedures does the supplier have for documenting and correcting problems?
Other accounts	Is the supplier heavily dependent on other customers, causing a risk of giving priority to those needs over ours?

on other criteria. If an audit reveals problem areas, a buyer can attempt to find a solution before more serious problems develop. Among the factors typically covered by a supplier audit are management style, quality assurance, materials management, the design process used, process improvement policies, and procedures for corrective action and follow-up.

Supplier audits are also an important first step in supplier certification programs.

Supplier Certification

Supplier certification is a detailed examination of the policies and capabilities of a supplier. The certification process verifies that a supplier meets or exceeds the requirements of a buyer. This is generally important in supplier relationships, but it is particularly important when buyers are seeking to establish a long-term relationship with suppliers. Certified suppliers are sometimes referred to as *world class* suppliers. One advantage of using certified suppliers is that the buyer can eliminate much or all of the inspection and testing of delivered goods. And although problems with supplier goods or services might not be totally eliminated, there is much less risk than with noncertified suppliers.

Rather than develop their own certification program, some companies rely on standard industry certifications such as ISO 9000, perhaps the most widely used international certification.

Supplier Relationships

Purchasing has the ultimate responsibility for establishing and maintaining good supplier relationships. The type of relationship is often related to the length of a contract between buyers and sellers. Short-term contracts involve competitive bidding. Companies post specifications and potential suppliers bid on the contracts. Suppliers are kept at arm's length, and the relationship is minimal. Business may be conducted through computerized interaction. Medium-term contracts often involve ongoing relationships. Long-term contracts often evolve into partnerships, with buyers and sellers cooperating on various issues that tend to benefit both parties. Increasingly, business organizations are establishing long-term relationships with suppliers in certain situations that are based on *strategic* considerations.

American firms have become increasingly aware of the importance of building good relations with their suppliers. In the past, too many firms regarded their suppliers as adversaries and dealt with them on that basis. One lesson learned from the Japanese is that numerous benefits derive from good supplier relations, including supplier flexibility in terms of accepting changes in delivery schedules, quality, and quantities. Moreover, suppliers can often help identify problems and offer suggestions for solving them. Thus, simply choosing and switching suppliers on the basis of price is a very shortsighted approach to handling an ongoing need.

Keeping good relations with suppliers is increasingly recognized as an important factor in maintaining a competitive edge. Many companies are adopting a view of suppliers as partners. This viewpoint stresses a stable relationship with relatively few reliable suppliers who can provide high-quality supplies, maintain precise delivery schedules, and remain flexible relative to changes in productive specifications and delivery schedules. A comparison of the contrasting views of suppliers is provided in Table 16.9.

TABLE 16.9
Supplier as adversary versus supplier as partner

Aspect	Adversary	Partner
Number of suppliers	Many; play one off against the others	One or a few
Length of relationship	May be brief	Long-term
Low price	Major consideration	Moderately important
Reliability	May not be high	High
Openness	Low	High
Quality	May be unreliable; buyer inspects	At the source; vendor certified
Volume of business	May be low due to many suppliers	High
Flexibility	Relatively low	Relatively high
Location	Widely dispersed	Nearness is important for short lead times and quick service

Supplier Partnerships

More and more business organizations are seeking to establish partnerships with other organizations in their supply chains. This implies fewer suppliers, longer-term relationships, sharing of information (forecasts, sales data, problem alerts), and cooperation in planning. Among the possible benefits are higher quality, increased delivery speed and reliability, lower inventories, lower costs, higher profits, and, in general, improved operations.

There are a number of obstacles to supplier partnerships, not the least of which is that because many of the benefits go to the buyer, suppliers may be hesitant to enter into such relationships. Suppliers may have to increase their investment in equipment, which might put a strain on cash flow. Another possibility is that the cultures of the buyer and supplier might be quite different and not lend themselves to such an arrangement.

Evaluating Shipping Alternatives

A situation that often arises in some businesses is the need to make a choice between rapid (but more expensive) shipping alternatives such as overnight or second-day air and slower (but less expensive) alternatives. In some instances, an overriding factor justifies sending a shipment by the quickest means possible, so there is little or no choice involved. However, in other instances, urgency is not the primary consideration, so there is a choice. The decision in such cases often focuses on the cost savings of slower alternatives versus the incremental holding cost (here, the annual dollar amount that could be earned by the revenue from the item being shipped) that would result from using the slower alternative. An important assumption is that the seller gets paid upon receipt of the goods by the buyer (e.g., through electronic data interchange).

The incremental holding cost incurred by using the slower alternative is computed as

$$\text{Incremental holding cost} = \frac{H(d)}{365} \qquad (16\text{–}1)$$

where

H = annual earning potential of shipped item

d = difference (in days) between shipping alternatives

EXAMPLE 1

Determine which shipping alternative, one day or three days, is best when the holding cost of an item is $1,000 per year, the one-day shipping cost is $40, and the three-day shipping cost is

a. $35 *b.* $30

SOLUTION

H = $1,000 per year

Time savings = 2 days using 1-day shipping

Holding cost for additional 2 days = $1,000 × (2/365) = $5.48

a. Cost savings = $5. Because the actual savings of $5 is less than the holding cost ($5.48), use the one-day alternative.

b. Cost savings = $10. Because the actual savings of $10 exceeds the savings in holding cost of $5.48, use the three-day alternative.

Operations Strategy

Two critical issues in supply chain management are recognition of its strategic importance, for cost, quality, agility, customer service, and competitive advantage, and technology management, for both its benefits and its risks.

There is much to be gained from successful management of a supply chain. Development of supply chain management capabilities should be given strategic importance in all business organizations.

Advances in information technology have enabled business organizations to make tremendous strides in managing their supply chains. However, all technology is not created equal.

There are major costs and risks related to technology acquisition, and understanding the intricacies and trade-offs often requires a level of expertise that is not possessed by many managers. Therefore, it is essential to get sound advice and then move cautiously in this area. And it is doubly important to recognize that technology vendors do not necessarily have the interests of potential buyers in mind when they make recommendations.

The purchasing function is critical to successful supply chain management. Increased outsourcing, increased conversion to lean production and just-in-time deliveries, and increased globalization have combined to make purchasing's role strategic.

SUMMARY

A supply chain consists of all the organizations, facilities, materials, and activities involved in producing and delivering a product or service, from the initial suppliers to the final customers.

Supply chain management represents a shift in focus for many business organizations. Until recently, firms tended to focus mainly on their own operations as they attempted to cut costs, improve quality, and meet delivery schedules. But because effective supply chain management offers the benefits of lower operating costs, reduced inventories, product availability, agility, and customer satisfaction, more and more firms are using supply chains to meet their objectives. Among the reasons for this shift are (1) the major internal improvements have been made; (2) outsourcing is increasing, which has led to higher transportation costs, a greater need to manage suppliers, and an increase in the importance of the purchasing function; (3) expanding global operations have increased the physical length of supply chains; and (4) the number of new products has increased, along with pressures for shorter product-development cycles, shorter lead times, and quick response.

The elements of supply chain management include customers, forecasting, product and service design, processing, inventory management, purchasing, supplier management, location decisions, and logistics.

Logistics involves the movement of goods and materials in a supply chain. This includes incoming materials, movement within a facility, and outgoing goods. It also includes overseeing the two-way flow of information across the supply chain.

The explosion of e-commerce business activities has introduced tremendous opportunities, and it underscores the importance of effective supply chain management. Electronic data interchange is being increasingly used for purchasing, order confirmation and payment, and arranging shipment. Companies adopt electronic data interchange to improve customer service, reduce cost, improve quality, and, in the process, gain a competitive edge.

Purchasing is the link between an organization and its suppliers. Purchasing selects suppliers, negotiates contracts, forges alliances, and serves as a liaison between the organization and its suppliers.

The objective of supply chain management is to be efficient across the entire supply chain. Among the difficulties in achieving this objective are barriers to integration, the need to deal with numerous trade-offs, variability of demand and lead times, and long lead times. Transactions between companies participating in supply chain management are based on mutual trust, long-term relationships, and shared information.

KEY TERMS

bullwhip effect, 696
centralized purchasing, 716
CPFR, 706
cross-docking, 711
decentralized purchasing, 716
delayed differentiation, 711
disintermediation, 712
distribution requirements planning (DRP), 700
e-commerce, 702
efficient consumer response (ECR), 700
electronic data interchange (EDI), 700
event management, 705
fill rate, 705
information velocity, 709
inventory velocity, 709
logistics, 697
outsourcing, 695
purchasing cycle, 714
strategic partnering, 708
supply chain, 693
supply chain visibility, 705
traffic management, 699
3-PL, 701
value analysis, 715
vendor analysis, 717

DISCUSSION AND REVIEW QUESTIONS

1. What is a supply chain?
2. What is the need to manage a supply chain, and what are some potential benefits of doing so?
3. What are the elements of supply chain management?

4. What are the strategic, tactical, and operations issues in supply chain management?
5. What is the bullwhip effect, and why does it occur? How can it be overcome?
6. Explain the increasing importance of purchasing.
7. What is meant by the term *inventory velocity* and why is this important? What is *information velocity*, and why is it important?
8. Explain strategic partnering.
9. What impact has e-commerce had on supply chain management?
10. What are some of the advantages of e-commerce?
11. What are some of the trade-offs that might be factors in designing a supply chain?
12. Locate an Internet website for a railroad that offers freight transportation, and determine the kinds of products it handles.
13. Explain the importance of supply chain visibility.
14. Describe CPFR.
15. Describe what purchasing managers do.
16. Describe how purchasing interacts with two other functional areas of an organization.
17. Describe value analysis. Why is the purchasing department a good location for this task?
18. Discuss centralization versus decentralization in purchasing. What are the advantages of each?
19. Describe vendor analysis.
20. Describe supplier certification and explain why it can be important.
21. Compare viewing suppliers as adversaries with viewing them as partners.

TAKING STOCK

1. What trade-offs are involved in (*a*) sharing information with other organizations in a supply chain and (*b*) the acquisition of information-processing technology?
2. Who needs to be involved in (*a*) decisions on technology acquisition for supply chain management and (*b*) supply chain management?
3. Name three different ways that technology has improved the ability to manage supply chains.

CRITICAL THINKING EXERCISE

Explain why each of these is critical for a successful supply chain operation:

a. Integrated technology
b. Information sharing
c. Trust among trading partners
d. Real-time information availability
e. Event management capability
f. Purchasing

PROBLEMS

1. A manager at Strateline Manufacturing must choose between two shipping alternatives: two-day freight and five-day freight. Using five-day freight would cost $135 less than using two-day freight. The primary consideration is holding cost, which is $10 per unit a year. Two thousand items are to be shipped. Which alternative would you recommend? Explain.
2. Determine which shipping alternative would be most economical to ship 80 boxes of parts when each box has a price of $200 and holding costs are 30 percent of price, given this shipping information: Overnight, $300, 2-day, $260, 6-day, $180.
3. A manager must make a decision on shipping. There are two shippers, A and B. Both offer a two-day rate: A for $500 and B for $525. In addition, A offers a three-day rate of $460 and a nine-day rate of $400, and B offers a four-day rate of $450 and a seven-day rate of $410. Annual holding costs are 35 percent of unit price. Three hundred boxes are to be shipped, and each box has a price of $140. Which shipping alternative would you recommend? Explain.

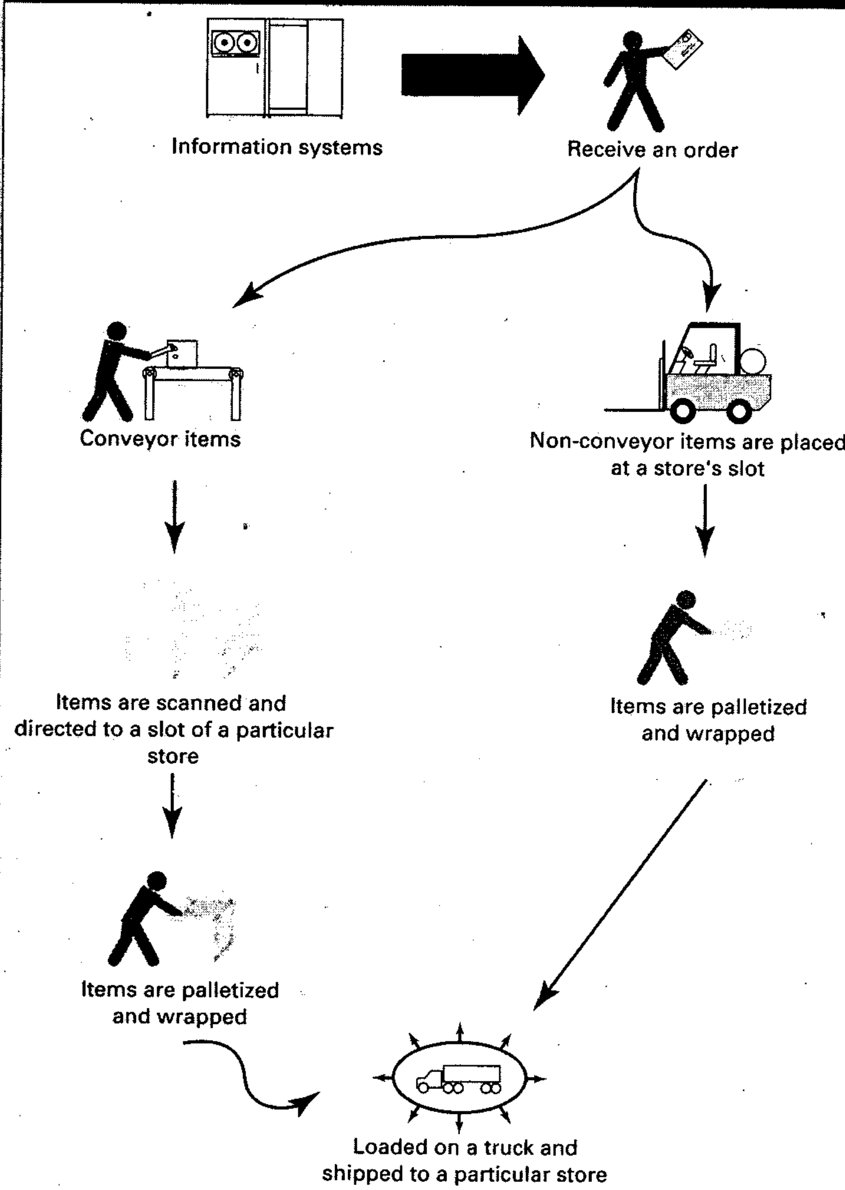
Wegmans' Distribution System

OPERATIONS TOUR

The Wegmans supermarket chain (see the Wegmans tour at the end of Chapter 1) has been cited as a leader in supply chain management in the grocery industry. Its distribution system provides a number of examples of strategies and tactics that contribute to its success in managing its supply chain.

Wegmans operates a number of warehouses that are used to supply its stores. Some warehouses stock grocery items, while others stock frozen foods, and still others stock bakery products, seasonal items, and/or produce. Even though all stores and warehouses are owned by Wegmans, the warehouses service the stores on a B2B basis.

Figure 1. Distribution Diagram



Distribution

Individual stores generate orders daily that are directed to the appropriate warehouses. Order fulfillment begins when a warehouse downloads a store's order to its information system. There are a variety of methods used to replenish stores' inventories. Several of these avoid the need for warehouse storage, saving the company storage and handling costs. Those methods are

1. *Cross dock*: A full inbound pallet is redirected to an outbound shipment.
2. *Cross distribution*: An inbound pallet is broken down into cases right on the dock, and then the cases are immediately distributed to outbound pallets.
3. *Vendor-managed inventory*: Vendors of some non–store brand items such as bread and soft drinks handle replenishment, and those items come directly from the vendor's warehouse to the stores.

Warehoused replenishment items are handled as full pallets, or broken down into cases, depending on quantities ordered:

1. *Block pick*: An entire pallet of goods in the warehouse is placed on an outbound truck.
2. *Case pick*: Individual cases or packages are pulled from inventory, placed on pallets and shrink wrapped, and then placed on outbound trucks.

Computerized information on incoming orders is checked against incoming shipments of stocks to determine which items can be filled using cross docking or cross distribution right in the

(continued)

(concluded)
loading area. These items are then subtracted from a store's order. The remaining items are filled from warehouse supplies.

Warehoused Items

Here is a brief description of retrieval of warehoused items in a dry goods (canned, boxed, etc.) warehouse: The system is semi-automated, and only a few workers are needed to process orders and monitor the system.

Warehoused items are classified for either conveyor belt or non–conveyor belt handling. Items are designated for conveyor belt handling based on their packaging and volume. If volume is low and packaging can withstand the conveyor belt, it will be assigned to the conveyor belt. If the packaging cannot withstand the conveyor belt, the items will be individually case-picked. Non–conveyor belt items that are high volume are automatically moved in bulk from their warehouse locations to a staging area to await loading onto an outbound truck.

When orders for conveyor belt items are received, a worker is given bar code labels that contain the number of the ordering store. The worker then goes to the section where an item is stored, affixes the appropriate store bar code, and places the item on the conveyor belt. As items move along the conveyer, their bar codes are scanned and they are sorted according to store number. After scanning and sorting, items move to staging areas where they are placed on pallets and shrink wrapped, and then placed in a slot designated for the appropriate store. The figure illustrates the handling of low-volume items.

Collaboration with Vendors

A desire to improve conveyer belt transporting has led Wegmans to collaborate with vendors in an effort to improve packaging design. Occasionally goods will fall off the belt, and those items have to be inspected to see if they have been damaged. Damaged goods not only are costly, they are lost from inventory and must be replaced. Improved packaging also increases the number of goods that can be handled with the conveyer system.

Forecasting

In 2002 Wegmans implemented its program of consistent, low pricing. This program reduced the number of promotional and sale items, reduced much of the volatility in demand, and made forecasting and inventory planning easier.

New Approaches

In 2003 Wegmans began exploring the use of auto-ID tags. The tags are very small micro chips, no bigger than a grain of salt. The tags are somewhat similar to bar codes, but offer greater potential for supply chain management because they can be more quickly read (e.g., multiple items can be scanned at once and, unlike bar codes, no line-of-sight is required for a reading), and scanning devices can be placed in warehouses and even on supermarket shelves that would warn when stocks of individual items are running low. The tags initially cost about $1 each, and currently cost about five cents each, making them cost effective for tracking shipments and bulk quantities of items, but still too costly to use on individual store items. However, they hold great promise for increasing supply chain visibility and event management capabilities.

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